VOL. 63 NO. 4

# JOURNAL

*of the*

# AMERICAN SOCIETY

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# NAVAL ENGINEERS, Inc.

NOVEMBER 1951

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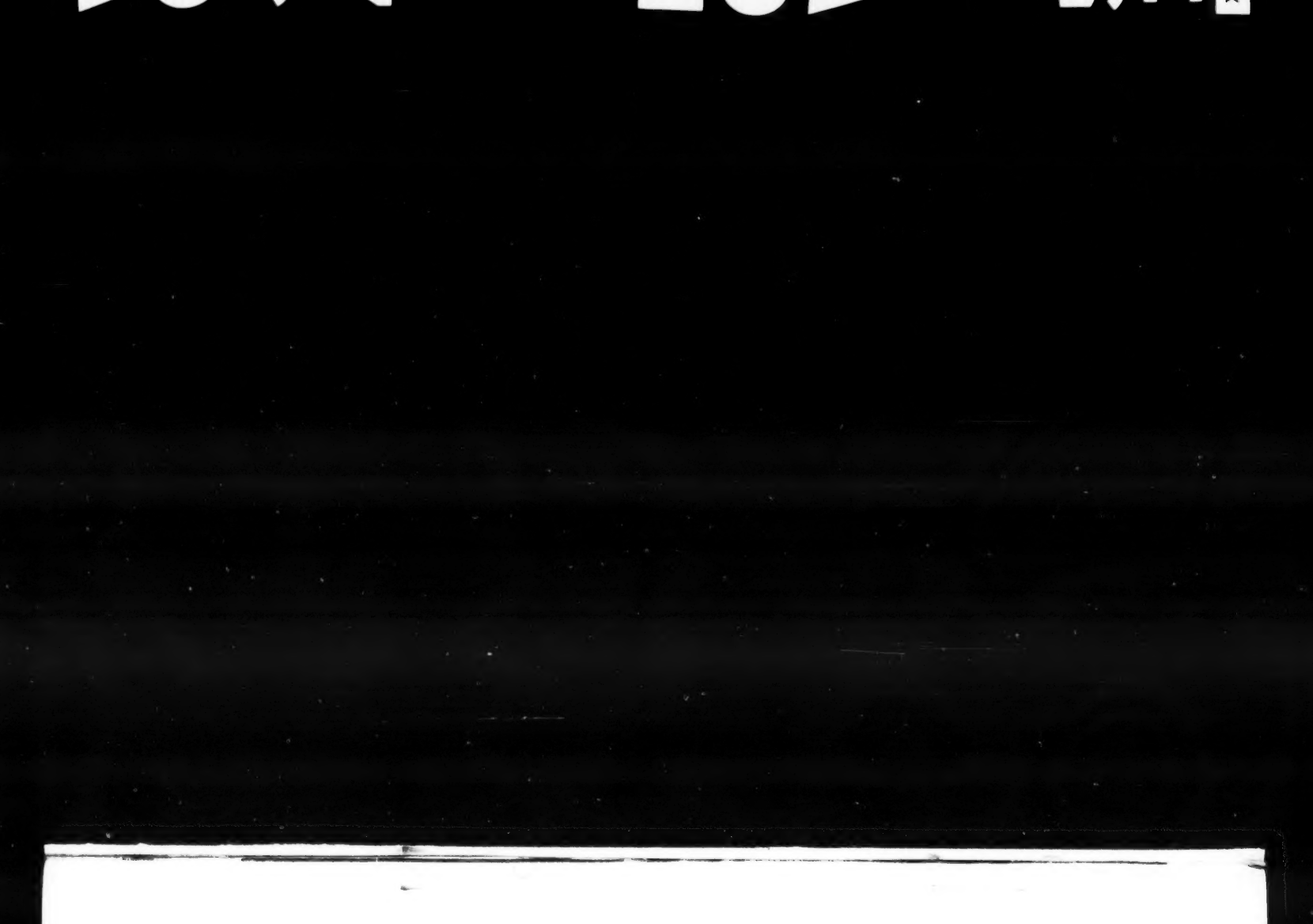

SUPPLEMENT
To
THE JOURNAL
Of
THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.
Vol. 63 No. 4

# SECRETARY'S NOTES (ADDENDUM)

## ANNUAL BANQUET

The Banquet Committee for 1952 held a meeting on 1 November, 1951. Certain decisions were reached as to arrangements for the next Annual Banquet which is to be held at the Statler Hotel, in Washington, D. C., on Friday, 2 May, 1952.

For the benefit of members who like to plan ahead, the following information is furnished at this time:

1. As in the past one non-member guest will be permitted for each member.

2. In order to permit as many as possible to attend the banquet, the full capacity of the hotel will be used if necessary. This means that it may be necessary to seat as many as 400 participants outside the two main rooms. However, precedence will be given in location of seats by the date of receipt of application. First applicants will be placed in the Presidential Room to its capacity, then in the Congressional Room, to its capacity. Remaining applicants will be placed outside.

The foregoing is subject to the following modifications:

(a) Every reservation, to be considered, must be made on the official form which will be mailed to members in late February or early March, and subject to conditions thereon.

(b) No application will be considered prior to 15 March, 1952. Precedence among those received as of that date will be decided by lot.

(c) No limit is placed on the size of parties, but no applicant shall be entitled to more than a limited number of tables in the Presidential and Congressional Rooms, regardless of date of receipt of application.

(d) A member of 20 or more years standing, who applies for himself only, or for himself and one guest only, will be seated in the Presidential Room to the limit of facilities, irrespective of date of receipt of application, up to the closing date for reservations.

No price for the banquet has been established at this time. In view of cost trends, it may be expected that it will be somewhat higher than the 1951 price. There will be a differential in charge for members and non-members.

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Vol. 63 November 1951 No. 4

Published Quarterly at Washington, D. C., by The American Society of Naval Engineers, Inc.

Entered as Second Class Matter at the Post Office at Washington, D. C. Acceptance for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 3, 1918.

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*Subscription Rates for Non-Members.*

The subscription price of the JOURNAL, postpaid to points in the United States and possessions is $9.00. Single copies, $2.25. To other countries, $10.00. Single copies, $2.50. All subscriptions payable in advance.

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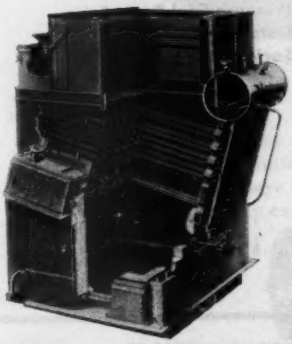

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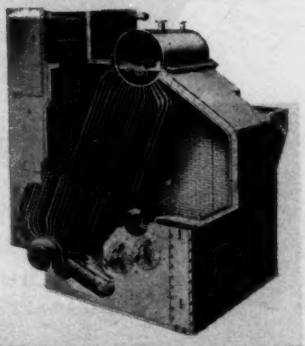

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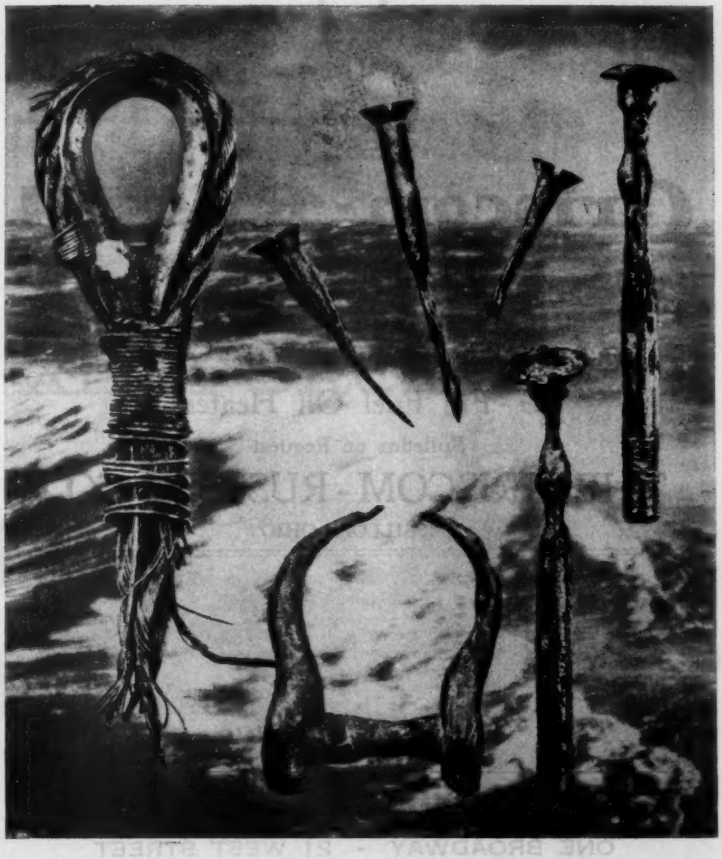

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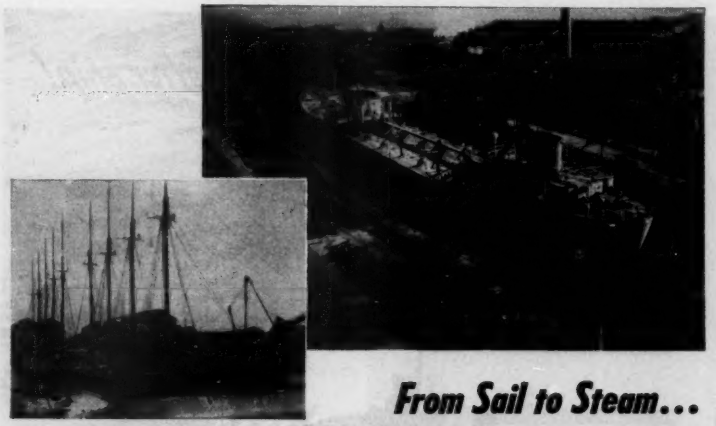

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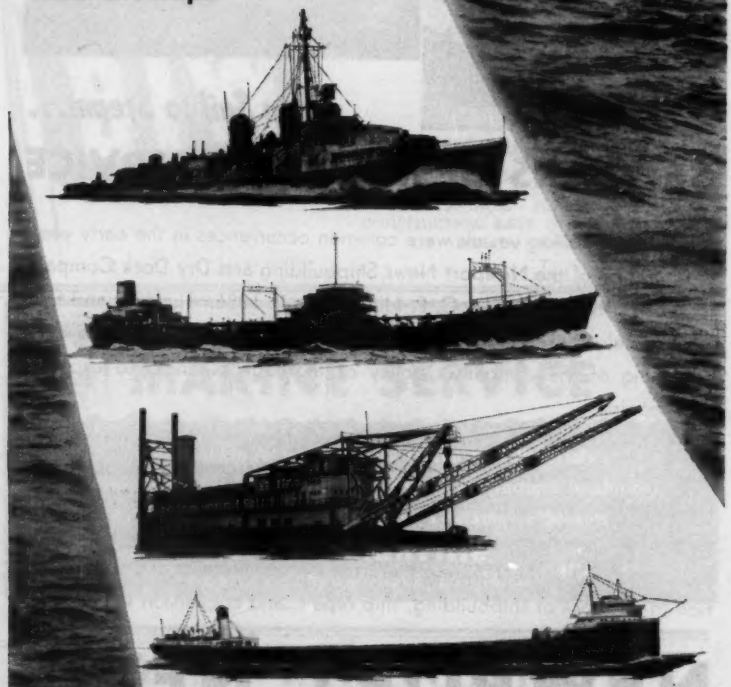

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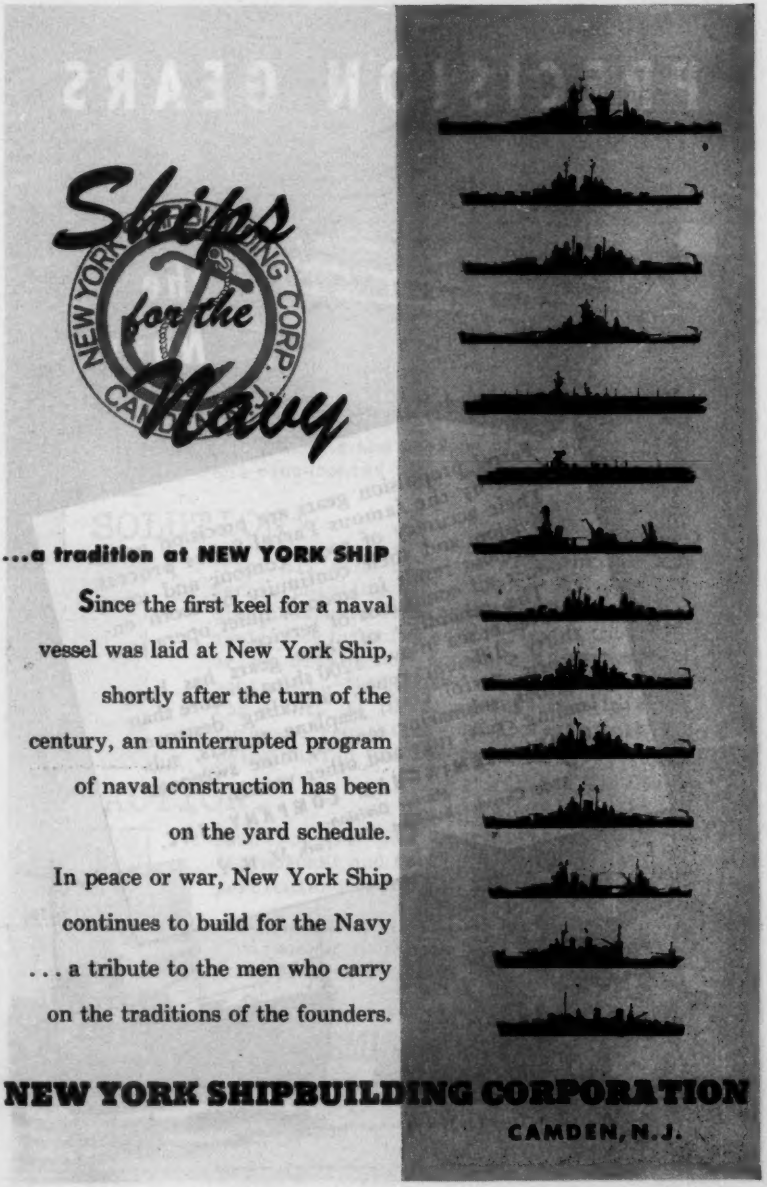
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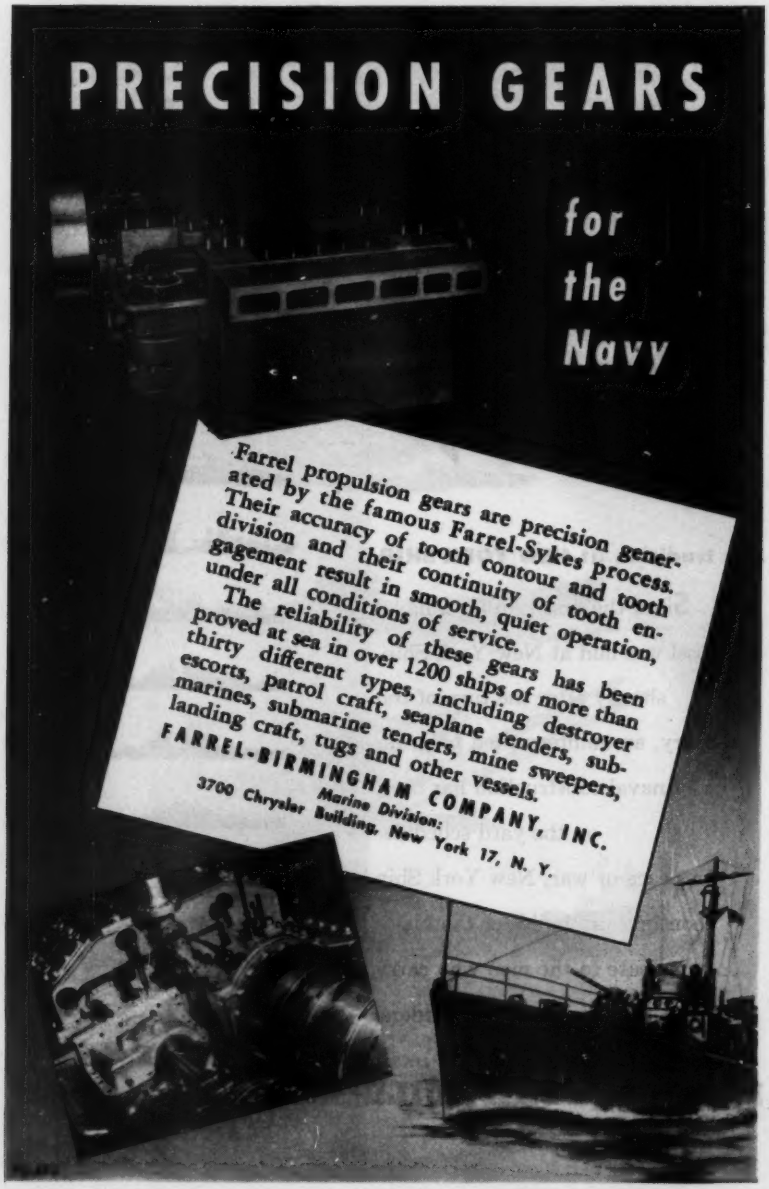
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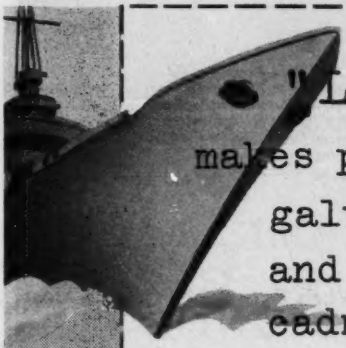

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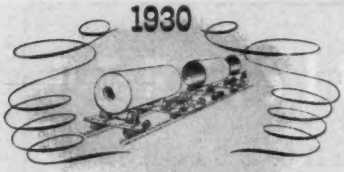


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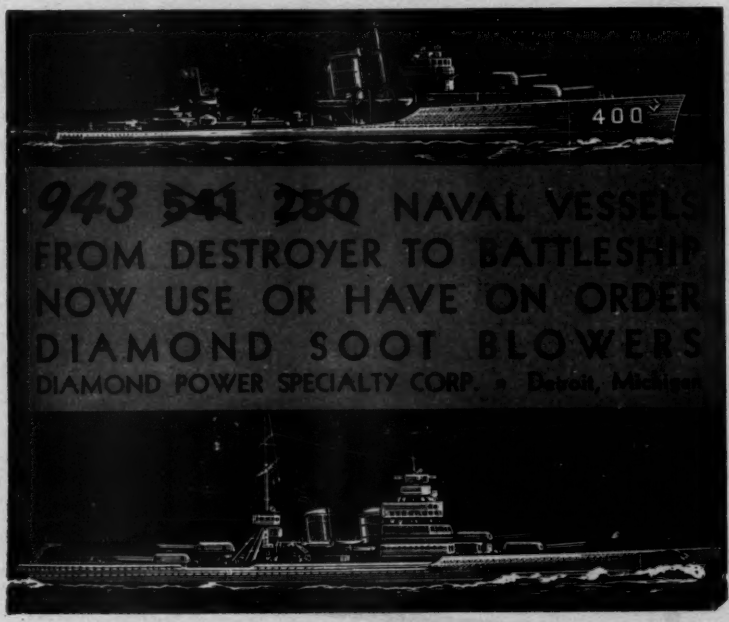


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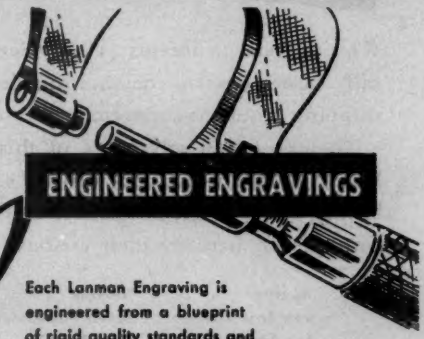

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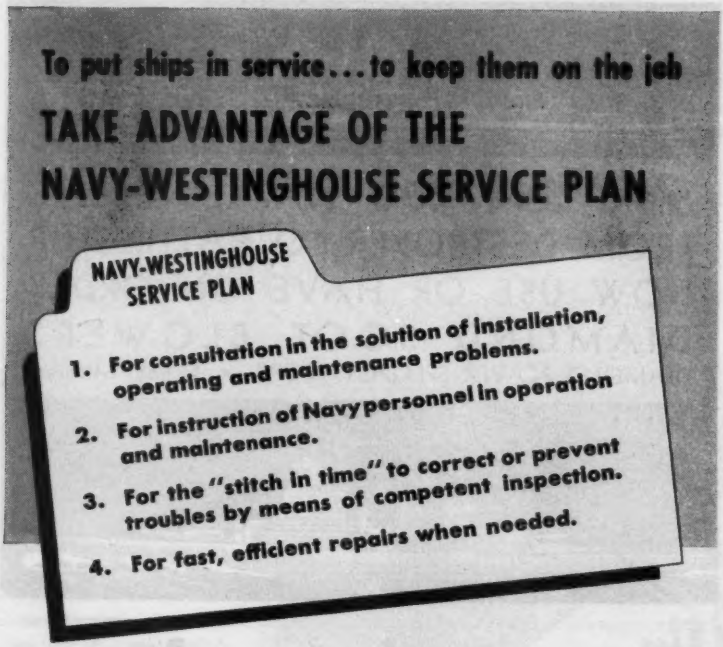
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JOURNAL
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VOL. 63. NOVEMBER 1951. No. 4

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## SECRETARY'S NOTES

### ANNUAL MEETING

The annual meeting of the Society was held, as required by the By-laws on 2 October 1951. Attendance was excellent.

### NOMINATION OF OFFICERS

The membership accepted the report of the nominating committee and made no additions thereto. Nominations were made for President, Secretary-Treasurer, and for candidates to replace the following Council members whose terms expire on 31 December 1951:

CAPTAIN RAWSON BENNETT, U.S.N.
CAPTAIN JOSEPH B. DUVAL, JR., U.S.N.
MR. FRANCIS H. ENGEL
CAPTAIN R. A. SMYTH, U.S.C.G.
CAPTAIN W. L. TANN, U.S.N.R.

Ballots will be on hand to members before this issue of the JOURNAL reaches them.

## Annual Banquet

Matters pertaining to the annual banquet were freely discussed. However the consensus of the meeting was that all details should be left in the hands of the Council. The Council continued the discussion at a meeting immediately following the annual meeting. Decision reached, after voting that the differential in cost of the banquet in favor of members should be continued, was to leave all other details in the hands of a Banquet Committee as has been customary in the past. The Banquet committee will be named by the president shortly and members will be advised of its actions through the usual banquet notice with application blank.

The 1952 banquet is scheduled to be held on Friday, 2 May 1952 at the Hotel Statler in Washington, D. C.

## Errata

It is regretted that the August issue of the Journal carried errors of a technically serious nature in two cases. It is hoped that placing the ERRATA in this place will cause it to be more easily spotted by readers.

Pipe Joint Bolt Stress. Potter and Eitel p. 547

Measurement and Analysis. Jasper p. 590

By some means the Figures 5 of these two articles became interchanged. The "Figure 5—Strain Cycle Analyzer and Gage" on page 547 pertains to the Jasper article and should have appeared at about page 590. Similarly, of course, the "Figure 5—Flange assembly in place, showing quick-opening valve, supporting tripod, by-pass line, and recording potentiometer" on page 590, is illustrative of the Potter-Eitel article and belonged on page 547.

Wave Drag of Ships. Kramer p. 576 and p. 578

A misplaced parenthesis in formula (8) on page 576 and missing parentheses in formula (19) on page 578 incorrectly state the formula. These should read:

Page 576 Formula (8)

$$D_w = \frac{I}{s} \times \left(\frac{B}{L}\right)^2 \times q^2 \times B$$

Page 578 Formula (19)

$$D_w = \frac{C}{s} \times \left(\frac{B}{L}\right)^2 \times q^2 \times B$$

## Society Business

Attention is invited to the report of an ad-hoc Committee which is published as a part of the Association notes. Action as recommended was, in general taken by the Council. Hence in 1952 we are committed to operating on a budget and within the Society's income. The secretarial staff will be strengthened to permit more aggressive membership and advertising campaigns than have been possible to date.

The report of the auditing committee for 1950 is also published in the Association Notes. Although the Society was operated at a loss in 1950, its net worth at the end of the year was very close to $60,000. The loss operation was planned by the Council and has been continued through the current year. The purpose was twofold: principally to provide an improved JOURNAL as recommended by Rear Admiral R. W. Paine, U.S.N. when he relinquished the presidency in 1948 and secondarily to reduce the surplus which was considered to be excessive.

It is now the opinion of the Council that both purposes have been served and that our operations should be on a strictly business basis hereafter. Every effort will be made to publish a good JOURNAL within our income. The quality of the JOURNAL, to the extent that it is determined by money, can be improved if an increased membership is available to increase the gross income. An increased membership with its attendant increased circulation will make the JOURNAL a more attractive advertising medium and should increase the income from advertising.

Captain Carl Lamb, USNR, a frequent contributor to the JOURNAL and a strong supporter of the Society attended the annual meeting from Houston, Texas where he is on active duty. Captain Lamb who alone has been responsible for some 20 new members advises all hands that he has found that the only action necessary to recruit members is to locate a candidate, show him the JOURNAL, and point out that he is eligible for membership. He suggests that this simple method be tested by each member. It is certainly easy to find civilians, inactive reservists, and regular and reserve officers on active duty who are fully eligible for membership and who have not exercised their privilege. If each member used Captain Lamb's method with only 10 percent of his effectiveness, the membership would triple overnight. It's worth a try.

JOURNAL

E. D. HISTORY

The staff has prepared a chapter in the history of the Engineering Duty Officers. This article beginning on page 751 covers, in that period between 1916 and 1940 the engineering branch of the group as it existed under the original 1916 legislation. It is the opinion of the Editor that this chapter along with previously published articles adequately covers the engineering branch from its beginning in 1862 with the Engineer Corps until its absorption in 1940. It is the further opinion of the Editor that the history of the Construction Corps is adequately covered from its beginning in 1842 until 1937, the date of publication of Rear Admiral Robert's History of the Construction Corps.

That leaves two gaps for which volunteer authors are needed. The first of these would cover the Construction Corps from 1937 until its absorption in 1940. The second would cover the very important events which attended the creation of the present ED group by the mutual absorption of CC and EDO officers, the development of the "Congineer" concept, and personalities and events of historical importance to EDs from 1940 to date.

Both of these chapters should be written in fairness to posterity and in recognition of the importance of the events to the Navy and to Naval Engineering.

There are two concomitant chapters which some authors owe to the world. They have to do with the development and growth of a microscopic sized group of civilian engineers some 35 years ago to the present corps of able civil servants who staff the material Bureaus of the Navy and who through the application to Naval Business of the special technical profession to which they have been called, are rapidly becoming the hard core of NAVAL Engineering; and the growth and development of the branch of the Naval Reserve which makes it possible to fill all engineering billets during emergency or war.

Four volunteers are requested. Address your offer to the Secretary-Treasurer.

NATHANIEL STEWART

Beginning on page 791, we publish what we think is a "mile stone" article. In the August 1951 issue of the JOURNAL we reproduced an article "The Developing Shortage of Engineers" by

Dean of the College of Engineering of Cornell University, S. C. Hollister. There have been several other articles published on this general situation.

Stewart's article describes the expedient action taken by one organization to meet this critical situation. It is, by no means, intended to imply that others have not taken or planned equally effective action. However, it is believed to be the first published description of a method of attack.

The action described by Stewart does not eliminate an impending shortage of engineers. It does do two things. First it proposes that types of work be carefully classified so that true engineers are employed on true engineering work. It is probable that many organizations are not utilizing engineers in the exercise of the talents which were developed by their education. Full development of this phase of the attack should clearly establish what the actual need for real engineers is. The second thing is to more clearly define the path to recognition as a true engineer for him whose formal education has been curtailed. With the approach to the profession clearly limned, but minor competition will be offered to the opportunities which are offered by engineering colleges. However, "commissioning from the ranks" if properly handled will bring a valuable element into the profession.

## Miscellaneous

### The "Practical Man."

The following paragraph, found in "THE CLARKSON LETTER" August-September 1951 intrigued the Editor. It is republished on the chance that others who might enjoy it and missed its other publications may have the opportunity.

### "The Practical Man"

The "practical man who rebels against theory at a time when industrial problems are becoming more complex will some day find himself unable to qualify for promotional opportunity ahead. He may be compared with the American Indians who taught the early settlers to put a fish in each hill of corn. All the Indian knew was that it produced a better crop—he did not know why. He was unprepared to apply his chance discovery to other crops because he lacked a knowledge of the theory of fertilization. The

chemist has long since learned why the Indian's corn was improved by the use of the fish. Practical farmers everywhere who are willing to listen to the chemist's theory have seen their fields yield more abundantly. An understanding of the principles underlying successful action enables us to predict with greater accuracy what will happen in a new situation. Our field of responsibility will not be limited to the areas bounded by past experience, if we make intelligent use of theory in our management activities.

—Wilbur M. McFeely,
In Bulletin of the National Council of Industrial Management Clubs."

# "DESIGNATED ENGINEERING DUTY ONLY"

## A Staff Article

*This article was prepared by the staff, using as principal references, Navy Registers and Registers of Graduates of the U.S. Naval Academy. It would be too much to expect that it will be free of errors and omissions. Any error or omission which is reported to the Secretary-Treasurer will be received with gratitude.*

On June 25, 1940 the Construction Corps of the United States Navy ceased to exist. Although the Corps with a proud, historically important background was eliminated, the personnel who constituted this able group were merely redesignated. By act of Congress they surrendered the designation of Naval Constructor and assumed the already existing designation "Engineering Duty Only." That act necessarily changed the constitution of the latter group.

The story of that amalgamation and the change in character of the EDO Group should be told, but it is not the subject of this article. We will, instead, lay on the record a brief account of the establishment and career of the original EDO Group without the existence of which the amalgamation could not have taken place in the way in which it was accomplished.

An official statement describes the initiation of the EDO Group in the following language:

"HISTORY OF THE ENGINEERS*

Engineers were seagoing personnel from the date of commissioning the first steam vessels of the Navy. After the organization of the Engineer Corps in 1859 they fought a continuous battle in the Navy Department and in Congress for recognition as operating personnel with rights to equal rank and promotion opportunities with the line. Despite this the Naval Academy from just after the Civil War to the Spanish-American War separately educated cadet midshipmen as line officers and cadet engineers as staff officers.

About 1897 strife between the line and the engineers reached such a pitch that the Navy Department, in an effort to restore harmony among its personnel, referred the questions at issue to a Naval Personnel Board, headed by Assistant Secretary of the Navy Theodore Roosevelt.

Animated by a strong desire to promote harmony within the Navy, 'Teddy' Roosevelt, in 1898, wrote a spirited report that advocated the amalgamation of

* Extracted from Navpers 10814 "BUSHIPS duty for Engineering Specialists."

the engineers with the line officers. The work of both classes of officers on shipboard, he said, was now largely of an engineering character, and for its proper performance it required officers with a considerable knowledge of engineering. 'Everything on such a vessel goes by machinery, and every officer, whether dealing with the turrets or the engine room, has to do with engineers' work. There is no longer any reason for having a separate body of engineers responsible for only a part of the machinery. What is needed is one homogeneous body, all of whose members are trained for the efficient performance of the duties of the modern line officer.'

In 1899 Congress passed the Naval Personnel Act, based upon the recommendations of the Naval Personnel Board, but containing some new provisions. This act contained the most important legislation concerning the engineers in the Navy that had been passed since the Civil War. Its most noteworthy provision related to the amalgamation of the line officers and the engineers. Younger engineers were permitted to qualify for general line duties, but the older ones were restricted to shore assignments and responsibilities involving their specialty.

At first these provisions did not work out as anticipated. The act apparently contemplated assignment of young officers to line and engineering duties indiscriminately, but in practice only a few of them were given the duties of engineers. For a time there was some agitation for the revival of the Engineer Corps. The Secretary of the Navy, however, opposed this view, holding that a 'persevering enforcement of the Naval Personnel Act' would provide a satisfactory engineering service at sea. His position was justified by the course of future events. By 1910 he was able to report that the new system was working satisfactorily; the line officers compared favorably as operating engineers with the officers of the old Engineer Corps and a sizable group of engineers drawn from the line was receiving training in marine engineering at Annapolis.

Initially the assignment of experienced line officers to 'engineering duty only' was to have been a temporary arrangement, but in 1916 Congress made this arrangement permanent. Such officers were to be carried as extra numbers in the line; and, except for certain staff duties afloat, after reaching the grade of commander they were to be limited to duties ashore."

That quotation is adequate for an official record, but it does not properly present in history the personal features and the principal personalities involved.

You will note that the amalgamation of the Construction Corps in the EDO Group took place during that period when, whether we knew it or not, we were actively preparing for the next war. The birth of the original EDO Group was in much the same environment. It occurred almost exactly twenty-three years before, when in 1916, the United States began actively preparing for its next war, which even then many people still did not believe would happen.

Responsibility for engineering design development in 1916 was placed in the Bureau of Steam Engineering and in its chief, the Engineer in Chief of the Navy. As the war clouds gathered, the position of Engineer in Chief was occupied by Rear Admiral R. S. Griffin who had spent his youth as a member of the Engineer Corps, USN. This Group was in a sense a counterpart of the Construction Group, but had been done away with by Congressional action, in this case not just before a war, but just after one, in 1899. Congress at that time had provided for the transfer of then active Engineer Corps officers to the line with limited duty (in

some cases) but made no provision for perpetuating the Naval engineering specialty. It apparently believed that the continuation of the Naval engineering art could be adequately handled by oncoming general line officers. It was certainly indicated in 1899 that the new Navy of mechanized steam ships would require that the line officers who operated them would have to have essentially the same familiarity with engineering operations as they did with gunnery and navigation. That, of course, has continued to be true but as both gunnery and navigation have assumed more the nature of operating engineering than of arts, the sea-going line officer today must be an operating engineer not, as was deemed necessary in 1899 of steam machinery only, but of practically all recognized branches of modern engineering.

The officers of the old Engineer Corps who remained in 1899 were not changed one iota by the change in designation but many of them, as the records will show, gave up their specialty, qualified for general line duties and their talents were lost to Naval engineering. Those who continued to be interested in matters of engineering design and development and hence did not qualify for general line duties continued to be assigned to duties where their talents could be applied to these subjects. As a matter of fact, as the general line officers developed into operating engineers a group of ex-Engineering Corps officers became available solely for assignment and duty ashore where they could devote themselves to the non-operating phases of the Naval engineering art. Such officers constituted the technical part of the Bureau of Steam Engineering. As a natural development, as the line officers with experience in engineering operation at sea became available for shore duty, some of them became the plexus in the Bureau of Engineering which maintained technical contact between engineering operations at sea and engineering and design development ashore.

Even though there was a slow but definite increase in the size of the Navy from 1899 onward, the gradual reduction in number of ex-Engineering Corps officers due to natural process of attrition did not produce an immediate effect. Attrition was slow and the numbers available for the ashore phase of the work increased percentagewise as the operating functions at sea were taken over by general line officers. Hence, the proper, true effect, of the elimination of the Engineer Corps, on advancing Naval engineering through design and development was slow in coming. Had it not come at all until the Engineer Corps nucleus was reduced to zero is not analyzable but it is predictable. That would have made essential that responsibility for technical advance in the engineering art be transferred almost entirely to civilian engineers. Since, prior to World War I, there were very few such civilians employed by the Navy, it is impossible to guess what the effect would have been to Naval engineering. It is certain from experience in many similar cases that had general line officers specialized in assignment of duty to the extent necessary to make them good design engineers and good developers of Naval engineering, they would have been denied adequate opportunity for sea duty and would have failed of promotion in many cases. Whether or not a corps of civilian engineers not subject to military discipline and not normally available for assignment to sea duty and without the basic indoctrination into the seagoing profession under the direction of operating Naval officers could have carried the standard is, of course, only subject to speculation. There are many reasons for believing that such a system might not have proven wholly adequate.

Regardless of what might have happened, what we propose is to discuss what did happen. In 1916 when, whether it knew it or not, the United States was getting ready for its first world war, an ex-Engineer Corps officer, Rear Admiral R. S. Griffin was Chief of the Bureau of Steam Engineering. Admiral Griffin served in that position through the war and until 1922, but he was next to the last Engineer Corps officer to serve as Chief of the Bureau. He was succeeded by three chiefs who were unrestricted line officers, but one of them, Rear Admiral J. K. Robison had been in the Engineer Corps. Another Engineer Corps officer on duty in the Bureau of Steam Engineering was Captain Charles W. Dyson who was the head of the Design Division. He retired as a Rear Admiral in 1925.

In 1899, the last Navy Register in which the Corps was reported listed 201 officers on active duty in the Engineer Corps. A detailed study of the careers of the officers would be of interest but the research necessary for such a task would be beyond the present capacity of the Staff.

According to the Register of Graduates of the U.S. Naval Academy, 65 of the 164 Naval Academy graduates who were Engineer Corps officers in 1899 were still on active duty in 1916. Of 37 non-Naval Academy graduates in 1899, 2 survived on active duty. Most of this group were senior in 1899 because until 1868 all engineers had come in from civilian life and after 1874 only two came in from that source, the last in 1879.

67 survivors of the Corps in 1916 seems a large number but it is apparent that a very small number of them were still limited to Engineering Duty. Included among the total were these 17 who were still restricted to shore duty. They apparently had not elected to qualify for general line duties.

| NAME | CLASS OF | RETIRED | DIED |
|---|---|---|---|
| Wythe M. Parks | —— | 1920 | 1938 |
| Reynolds T. Hall | —— | 1922 | 1934 |
| Walter F. Worthington | 1875 | 1919 | 1937 |
| George W. McElroy | 1878 | 1922 | 1931 |
| Robert S. Griffin | 1878 | 1921 | 1933 |
| Frank W. Bartlett | 1878 | 1920 | 1932 |
| George E. Burd | 1878 | 1921 | 1924 |
| Benjamin C. Bryan[1] | 1879 | 1922 | 1930 |
| Harold P. Norton[2] | 1879 | 1919 | 1933 |
| Clarence A. Carr | 1879 | 1920 | 1930 |
| Thomas W. Kinkaid | 1880 | 1920 | 1920 |
| William Strother Smith | 1880 | 1921 | 1927 |
| Gustav Kaemmerling | 1881 | 1922 | 1934 |
| Kenneth McAlpine | 1881 | 1919 | 1923 |
| Emil Theiss[3] | 1882 | —— | 1917 |
| Robert B. Higgins | 1882 | 1921 | 1928 |
| Charles W. Dyson | 1883 | 1925 | 1930 |

[1] President of the Society 1907, Secretary-Treasurer of the Society 1901.
[2] President of the Society 1917, 1918, 1919.
[3] Secretary-Treasurer of the Society 1891.

## "DESIGNATED ENGINEERING DUTY ONLY"

Although some of them had made a real mark as engineers, most of the 47 listed below were certainly well enough recognized as general line officers, as to make it unrealistic to consider them, no matter how talented they may have been basically as engineers, as available for assignment to highly technical Naval engineering billets.

| NAME | CLASS OF | RETIRED | DIED |
|---|---|---|---|
| Frank M. Bennett | 1879 | 1919 | 1924 |
| Alexander S. Halstead | 1883 | 1923 | 1949 |
| Josiah S. McKean | 1884 | 1928 | —— |
| Edward L. Beach | 1888 | 1921 | 1943 |
| Herman O. Stickney | 1888 | 1921 | 1936 |
| Louis M. Nulton | 1889 | 1933 | —— |
| Cleland N. Offley | 1889 | 1922 | 1930 |
| Douglas E. Dismukes | 1890 | 1925 | 1949 |
| Urban T. Holmes [1] | 1890 | 1917 | 1940 |
| Claude B. Price | 1890 | 1921 | 1922 |
| Milton E. Reed | 1891 | 1925 | 1932 |
| George W. Laws | 1891 | 1934 | 1945 |
| John K. Robison | 1891 | 1926 | 1938 |
| Stanford E. Moses | 1892 | 1927 | 1950 |
| Edward S. Kellogg | 1892 | 1927 | 1948 |
| Robert K. Crank | 1892 | —— | 1918 |
| Raymond D. Hasbrouck | 1892 | —— | 1926 |
| John R. Brady | 1893 | 1917 | 1946 |
| Henry B. Price | 1893 | 1925 | 1941 |
| Martin E. Trench | 1893 | 1925 | 1927 |
| Andre M. Proctor | 1893 | 1928 | 1938 |
| Chester Wells | 1893 | 1924 | 1948 |
| Roscoe C. Moody | 1894 | 1927 | 1933 |
| Alfred W. Hinds | 1894 | 1927 | —— |
| Joseph M. Reeves | 1894 | 1936 | 1948 |
| Frank Lyon | 1894 | 1929 | 1949 |
| Hutch I. Cone | 1894 | 1922 | 1941 |
| Franklin D. Karns | 1895 | 1931 | —— |
| Frederic N. Freeman | 1895 | Dismissed | 1918 |
| James P. Morton | 1895 | 1922 | 1928 |
| Gatewood S. Lincoln | 1896 | 1931 | —— |
| Albert W. Marshall | 1896 | 1938 | —— |
| Kenneth G. Castleman | 1896 | 1935 | —— |
| William L. Littlefield | 1896 | 1931 | 1935 |
| Pope Washington | 1896 | 1918 | 1935 |
| Arthur Crenshaw | 1896 | —— | 1921 |
| Louis C. Richardson | 1897 | 1931 | 1937 |
| Andrew T. Graham | 1897 | 1939 | 1939 |
| Henry N. Jenson | 1897 | 1924 | 1941 |
| William D. Leahy | 1897 | —— | —— |
| Fletcher L. Sheffield | 1898 | —— | 1930 |
| William B. Wells | 1898 | 1929 | 1930 |
| Edward T. Constien | 1898 | 1931 | 1949 |

| NAME | CLASS OF | RETIRED | DIED |
|---|---|---|---|
| John S. Graham | 1898 | 1925 | —— |
| Alexander N. Mitchell | 1898 | 1917 | 1929 |
| Louis Shane | 1898 | 1934 | 1941 |
| Henry C. Dinger [2] | 1898 | 1930 | —— |

[1] Secretary-Treasurer of the Society 1911.

[2] Secretary-Treasurer of the Society 1909, 1910, 1914.

Three survivors of the 1899 group were identified with other special groups as follows:

Professor of Mathematics, Daniel M. Garrison, Class of 1895, Retired 1923, Died 1927.

U. S. Marine Corps, George Van Orden, Class of 1897, Retired 1923.

Construction Corps, Henry T. Wright, Class of 1898, Retired 1939.

We are interested specifically in the first group of 17 officers. To what extent retirement laws in 1916 permitted forecasting events is of minor importance. It is important that as of 1916 this group had future active naval service limited as follows:

| | | | |
|---|---|---|---|
| 1 year | 1 | remaining in 1918 | 16 |
| 3 years | 5 | remaining in 1920 | 11 |
| 4 years | 3 | remaining in 1921 | 8 |
| 5 years | 4 | remaining in 1922 | 4 |
| 6 years | 3 | remaining in 1923 | 1 |
| 9 years | 1 | remaining in 1926 | 0 |

It is thus apparent that for an officer group to handle engineering matters through what proved to be the largest shipbuilding program the United States had ever had up until that time, there were only a handful of specialists left to guide and leaven the work of those general line officers who either through natural preference or the vagaries of the Bureau of Navigation were assigned to engineering duty.

Among this latter group in the Bureau of Steam Engineering was Lieutenant S. M. Robinson, USN, a graduate of the Naval Academy, Class of 1903. Robinson seems to have given the matter serious consideration and conceived the idea, probably based on his own preference, of forming a new group of engineering specialists who would still have the advantages of being line Naval officers. Not only would they serve out their careers as line Naval officers, but they would be recruited from among interested young line officers who wished to specialize in engineering matters and who needed only career protection to permit them to do it. Robinson was well acquainted with the history of the Engineering Corps and knew that any proposal to resurrect it, even though it might seem desirable to some, would fall on deaf ears. As a matter of fact, he was in a position to see that the requirement that general line officers have the broadening experience of engineering operation at sea was extremely valuable to the Navy. There was no reason for taking a backward step in that regard. All that was needed was a means of attracting straight line officers who wished to specialize in engineering without, at the same time, jeopardizing their future careers in the Navy.

Robinson, after thinking the matter out, started wheels rolling which produced the following statute:

## EXCERPT FROM PUBLIC LAW NO. 241—64th CONGRESS

Approved August 29, 1916

"OFFICERS FOR ENGINEERING DUTY ONLY

Officers of the line of the Navy not below the grade of lieutenant may, upon application, and with the approval of the Secretary of the Navy, be assigned to engineering duty only, and that when so assigned and until they reach the grade of commander, they shall perform duty as prescribed in section four of the Personnel Act approved March third, eighteen hundred and ninety-nine, and thereafter shore duty only as now prescribed for officers transferred to the line from the former engineer corps, except that commanders may be assigned to duty as fleet and squadron engineers: *Provided,* That when so assigned they shall retain their place with respect to other line officers in the grades they now or may hereafter occupy, and also the right to succession to command on shore in accordance with their seniority, and shall be promoted as vacancies occur subject to physical examination and to such examination in engineering as the Secretary of the Navy may prescribe: Provided further, That the number of officers so assigned in any one year shall be in accordance with the requirements of the service as determined by the Secretary of the Navy: *And provided further,* That the Secretary of the Navy is hereby authorized to appoint annually in the line of the Navy for a period of ten years following the passage of this Act, in the order of merit determined by such competitive examination as he may prescribe, thirty acting ensigns for the performance of engineering duties only. Persons so appointed must have received a degree of mechanical or electrical engineer from a college or university of high standing or be graduates of technical schools approved by the Secretary of the Navy, must have been found physically qualified by a board of medical officers of the Navy for the performance of the duties required, and must at the time of appointment be not less than twenty nor more than twenty-six years of age. Such appointments shall be for a probationary period of three years, and may be revoked at any time by the Secretary of the Navy.

Such acting ensigns shall, upon the completion of the probationary period of three years, of which two years shall have been spent on board cruising vessels and one year pursuing a course of instruction at the Naval Academy prescribed by the Secretary of the Navy, be commissioned in the grade of lieutenant of the junior grade after satisfactorily passing such examination as may be prescribed by the Secretary of the Navy, and having been recommended for promotion by the examining board and found physically qualified by a board of medical officers of the Navy.

Such officers shall thereafter be required to perform engineering duties only, and shall be eligible for advancement to the higher grades in the manner herein provided for line officers assigned to engineering duty only."

This statute was one of the provisions of the National Defense Act of 1916 along with many other provisions intended to place the United States in a position

to meet whatever might develop because of the broadening of the European war. The actual wheels which rolled after Commander Robinson gave the first push are apparent from the following informal description of events.

The first act was for Robinson to reduce his thinking to words which he did, acting as his own typist. The words which flowed from his hand with few exceptions are those which appeared in the legislation which has just been cited. It then took a combination of the triumvirate which I have mentioned to turn the next wheel. Robinson occupied a relatively junior position in the Bureau of Steam Engineering but in spite of it he approached the Chief personally. His approach was probably too abrupt or his introduction of the matter careless because the first impression made on Admiral Griffin was that Robinson was proposing something which was in the province of the Chief of the Bureau of Navigation and not his own. As a Naval officer of wide experience he could not bring himself to action which might appear to be a subtle means of indicating dereliction on the part of a brother chief of bureau. His thinking, of course, in this regard, was more or less conventional since Congress, in abolishing the Engineer Corps had made the matter of filling engineering billets ashore and afloat the responsibility of the Chief of the Bureau of Navigation and not of the Chief of the Bureau of Steam Engineering. Admiral Griffin himself, up to that time, had had no complaint as to the officer assistance which had been provided to him by the Bureau of Navigation and probably had not seen the possibility that his satisfaction was due, at least in part, to the continued existence of a handful of Engineer Corps officers and the additional fact that the younger line officers whom he had been given, like Robinson, had not yet begun to feel the career pinch of having to get away to sea duty, free from engineering, to protect their positions.

At any rate, Admiral Griffin was lukewarm to Robinson's brain child until Captain Dyson, who, in addition to being a brother ex-Engineer Corps officer, was a close personal friend, has assimilated and approved the Robinson proposal and had personally convinced the chief that he could safely put the proposal forward with no reflection on the Chief of the Bureau of Navigation, the Congress which had abolished the Engineer Corps or anyone else. As soon as he was convinced, Admiral Griffin lost no time in pushing the next wheel.

We have discussed the Naval triumvirate which had a part in the establishment of the Engineering Duty Only group. These three and their relationship to the Navy and to the American Society of Naval Engineers are of interest. Each of the three was both Secretary-Treasurer and then President of the Society, Griffin having been the first Secretary in 1899 and having been reelected to the position in 1894 and 1895. He became President in 1908, 1912, and 1913. Dyson was the seventh Secretary in 1902 and was elected President in 1916, 1920, and 1922. Robinson was appointed Secretary in 1921 and was elected to the position in 1922 and 1923. He served as President in 1931.

Both Griffin and Dyson retired as rear admirals, Griffin having been the last ex-Engineering Corps officer still specializing in engineering to serve as the Chief of the Bureau of Steam Engineering and Dyson the last such officer on the active list. Robinson is the only Naval engineer * ever to have retired as a full four star admiral and has the distinction of having been the first EDO to serve as the Chief of the Bureau of Engineering since the chiefs who followed Admiral Griffin were

* Admiral Ben Morreel, *Civil* Engineer Corps shares this distinction.

all from the unrestricted line officer group. He has the further distinction of being the first Chief of the Bureau of Ships and the first occupant of the position which developed into the Chief of Naval Materiel.

The Careers of Griffin and Dyson were epitomized by the Society which published "Appreciations" written by a former Chief Engineer of the Navy, Walter M. McFarland, on their deaths in 1933 and 1931, respectively. A perusal of these "Appreciations" leaves no doubt of the outstanding qualities of Griffin and Dyson as Naval Engineers, as Naval officers, and as citizens.

As previously mentioned, once he had taken hold of the idea, Admiral Griffin pursued it assiduously. His approach, through circumstances, was somewhat unconventional, but highly effective. First he is to be given credit for having inserted in the proposed legislation the provision that Engineering Duty Only officers could succeed to command ashore. Having decided on the details of the proposed law which he could support, he mentioned the matter to the Secretary of the Navy, the dynamic and forthright, Josephus Daniels who, in spite of what his detractors may have had to say about him, as a strong Secretary of the Navy has had few superiors in his active and forceful support of the Navy as a national institution. Typical of him was his reaction when Admiral Griffin mentioned the proposal. He merely took the piece of paper and put it in his pocket after indicating that he thought it was a good idea.

Among other qualifications of Josephus Daniels was the very fine working relationship which he had with the Naval Affairs Committees of the Senate and House of Representatives. He was assisted in his processing of the legislation by the fact that the National Defense Act of 1916, at the moment, had passed the House of Representatives and was under consideration in the Senate Naval Affairs Committee. Daniels, with little delay, still with the piece of paper in his pocket, paid a visit to Senator Ben Tillman, Chairman of the Senate Naval Affairs Committee, and suggested to him that he sponsor the legislation. That was practically the end of the matter. The Senate added the legislation, which is quoted above, to the National Defense Act. It was accepted by the House on advice of its Naval Affairs Committee under the able chairmanship of Representative Lemuel P. Padgett. Probably Daniels had seen Padgett in connection with this matter, but whether or not he did, his sale of the idea to Senator Tillman was adequate. In one of the houses of Congress, the provision that officers could be taken in from civilian life as Engineering Duty Only was added and the legislation was complete as cited above.

This rather informal method of doing business, which in effect was Robinson to Dyson to Griffin to Daniels to Tillman to Padgett, resulted in a legislative provision which was very far reaching in its consequences. It provided for continuity in engineering design and development of Naval officers who were interested in that phase of their profession. As evidenced by the rank attained by those EDOs who survived, it is fairly evident that the legislation provided adequately for the careers of those who elected to join the EDO group. That the legislation contributed to the effectiveness of the Navy is difficult to prove by specific examples. However, the success of the Navy in World War II was due, in some part, at least, to the fact that its ships took second place to none in either the quality of their basic engineering plants or the quantity and quality of effective engineering gadgetry which they carried. Much of this must certainly be credited to a group of Naval officers who were enthusiastic enough about the engineering profession

to surrender the more outwardly glamorous phase of a line officer's career. From the date of the inauguration of the EDO Group until the present time, officers in the EDO Group occupied many of the principal billets in the Bureau of Engineering and its successor, the Bureau of Ships, and equally important positions in Naval shipyards, Naval inspection offices, and in the supervision of construction of Naval vessels and installation of their machinery.

A secondary benefit of the existence of the EDO Group is that when the decision was reached to amalgamate the Bureau of Construction and Repair and the Bureau of Engineering into the Bureau of Ships and to concurrently amalgamate the two related technical groups, namely the Construction Corps and the EDO Group, the mechanics for doing it were provided in the established existence of the EDO Group whose regular status and administrative qualifications provided adequately for absorption into it or by the officers in the Construction Corps.

As a concluding element in this paper, we might take a look at the individuals who were included in the original EDO Group. The first group so designated in the Naval Register, 1918 naturally included Lieut. S. M. Robinson. The others were:

| | |
|---|---|
| *Capt. Cleland N. Offley | Class of 1889 |
| *Com. Henry C. Dinger | Class of 1898 |
| Com. Hellis T. Winston | Class of 1900 |
| Com. William Norris | Class of 1901 |
| Com. Joseph Otto Fisher | Class of 1902 |
| Com. Carlos Bean | Class of 1902 |
| Com. Roscoe C. Davis | Class of 1902 |
| Lt. Com. Nathaniel H. Wright | Class of 1904 |
| Lt. Com. Clyde S. McDowell | Class of 1904 |
| Lt. Com. Ormond L. Cox | Class of 1905 |
| Lt. Com. Albert T. Church | Class of 1905 |
| Lt. Com. Harold G. Bowen | Class of 1905 |
| Lt. Com. Charles A. Dunn | Class of 1907 |
| Lt. Com. Bryson Bruce | Class of 1907 |
| Lt. Com. Sydney M. Kraus | Class of 1908 |

* Ex-Engineer Corps.

Although not carried in the 1918 list, Com. Louis Shane, Class of 1898 and an ex-Engineer Corps officer, also became an EDO. Thus but 3 of 65 survivors of the old Engineer Corps in 1916 became officially designated as members of the new EDO Group.

Following the original selection for transfer from the regular Navy, another group was taken in from civilian life. Of these, the following survived to be designated EDO and made contributions, at least equal in the average, to those of the ones who were taken from the regular Navy.

Sidney B. Blaisdell
Harry L. Dodson
Roy W. Bruner
Duane L. Taylor
Roger F. McCall
Richard C. Bartlett
Louis Dreller

## "DESIGNATED ENGINEERING DUTY ONLY"

In addition to the 23 "originals" just listed about 82 * other regular Naval officers were added to the list of those designated "For Engineering Duty Only" during that phase when entry into the group was governed by the 1916 Act of Congress which might be designated as Robinson to Dyson to Griffin to Daniels to Tillman to Padgett.

The full import of the group of officers who were designated for "Engineering Duty Only" can perhaps be approached only by studying the biography of each one. Many of the members are fairly well known in naval and industrial circles. Since 1916, with two exceptions, and those for only a few months, every Secretary of the Society has been from this group and eight presidents have been included. Of the six Chiefs of Bureau of Ships and six deputies since its establishment, three chiefs and three deputies have been members of the basic EDO group. Of the total number of EDO's in the period under discussion 14 are still alive:

These are:

Rear Admiral David H. Clark, Class of 1919
President of the Society in 1951 and ex-Chief of the Bureau of Ships
Rear Admiral Hugh E. Haven, Class of 1920
Rear Admiral Wilson D. Leggett, Class of 1921
Present Deputy Chief of the Bureau of Ships
Rear Admiral Logan McKee, Class of 1921
Captain William R. Millis, Class of 1921
Captain Hyman G. Rickover, Class of 1922
Captain E. C. Forsyth, Class of 1922
Captain Peter W. Haas, Jr., Class of 1923
Captain Fred W. Walton, Class of 1923
Secretary of the Society 1945-1948
Captain Pleasant D. Gold, 3rd, Class of 1923
Captain Homer Ambrose, Class of 1923
Captain LeRoi B. Blaylock, Class of 1924
Captain Max Schreiner, Class of 1924
Captain William C. Latrobe, Class of 1925

Of the remaining 89, 30 attained flag rank, as follows:

Admiral Samuel M. Robinson, Class of 1903, Retired 1946
Ex-Chief of the Bureau of Engineering; ex-Chief of the Bureau of Ships; President of the Society of 1939; Secretary-Treasurer of the Society, 1921-1923
Vice Admiral Harold G. Bowen, Class of 1905, Retired 1947
Ex-Chief of the Bureau of Engineering; President of the Society 1938
Vice Admiral Earle W. Mills, Class of 1918, Retired 1949
Ex-Deputy Chief and Chief of the Bureau of Ships; President of the Society 1945.
Rear Admiral Paul B. Dungan, Class of 1899, Retired 1941, Died 1941
Rear Admiral Ivan Bass, Class of 1901, Retired 1941
Rear Admiral Ormand L. Cox, Class of 1905, Retired 1946
Secretary-Treasurer of the Society, 1913, 1928, 1931
Rear Admiral Albert T. Church, Class of 1905, Retired 1943

* 82 names have been gleaned from Naval Registers. *"About* 82" is used because of the probability of error by using this source.

Rear Admiral Stanford C. Hooper, Class of 1905, Retired 1943
Rear Admiral Harry A. Stuart, Class of 1904, Retired 1943, Died 1949
Rear Admiral Charles A. Dunn, Class of 1907, Retired 1947
Rear Admiral Bryson Bruce, Class of 1907, Retired 1946
Secretary-Treasurer of the Society 1924-25
Rear Admiral Claude A. Jones, Class of 1907, Retired 1946, Died 1948
Ex-Deputy Chief of the Bureau of Ships; President of the Society 1941
Rear Admiral Alexander M. Charlton, Class of 1908, Retired 1946
Secretary-Treasurer of the Society 1926
Rear Admiral Sydney M. Kraus, Class of 1908, Retired 1948
The aeronautical engineering pioneer who became an A.E.D.O.
Rea. Admiral Joseph J. Broshek, Class of 1908, Retired 1946
President of the Society, 1943
Rear Admiral Frank J. Wille, Class of 1908, Retired 1947
Rear Admiral James M. Irish, Class of 1908, Retired 1946
Rear Admiral Albert M. Penn, Class of 1908, Retired 1945, Died 1947
Rear Admiral Timothy J. Keleher, Class of 1908, Retired 1943
Rear Admiral Harold T. Smith, Class of 1909, Retired 1946
Secretary-Treasurer of the Society 1929-1930
Rear Admiral Claude S. Gillette, Class of 1909, Retired 1946
Secretary-Treasurer of the Society 1935-36
Rear Admiral Sherman S. Kennedy, Class of 1909, Retired 1948
Rear Admiral Roger W. Paine, Class of 1911, Retired 1949
President of the Society 1948; Secretary-Treasurer of the Society 1936-1938
Rear Admiral Thorvold A. Solberg, Class of 1916, Retired 1951
President of the Society 1949
Rear Admiral Louis Dreller, Retired 1951
President of the Society 1951
Rear Admiral Paul F. Lee, Class of 1919, Retired 1948
Rear Admiral Edgar P. Kransfelder, Class of 1920, Retired 1950
Commodore Webster M. Thompson, Class of 1916, Retired 1947
Commodore Lisle F. Small, Class of 1917, Retired 1947
Commodore Jennings B. Dow, Class of 1920, Retired 1947
Captain William E. Sullivan, Class of 1921, Died 1950
Was selected for promotion to Rear Admiral but died before promotion

Just to make the record complete these officers, not included above gained the designation "Engineering Duty Only" between the origin of the group and the 1940 legislative change:

Captain Cleland N. Offley, Class of 1889, Retired 1922, Died 1930
Captain David F. Boyd, Class of 1897, Retired 1932
Captain Henry C. Dinger, Class of 1898, Retired 1930
Secretary-Treasurer of the Society 1909, 1910, 1914
Captain Louis Shane, Class of 1898, Retired 1934, Died 1941
Lt. Cdr. Hollis T. Winston, Class of 1900, Retired 1922, Died 1938
Captain William Norris, Class of 1901, Retired 1929, Died 1933
Captain Roscoe C. Davis, Class of 1902, Retired 1937
Captain Carlos Bean, Class of 1902, Retired 1935, Died 1937
Captain Joseph O. Fisher, Class of 1902, Retired 1928, Died 1933
Cdr. Francis J. Cleary, Class of 1903, Retired 1931

Captain Nathaniel H. Wright, Class of 1904, Retired 1938, Died 1940
Captain Clyde Stanley McDowell, Class of 1904, Retired 1937
Captain Albert Norris, Class of 1905, Retired 1939
Captain Edgar G. Oberlin, Class of 1905, Retired 1932
Cdr. Robert L. Irvine, Class of 1905, Retired 1933
Captain Halford R. Greenlee, Class of 1905, Retired 1940
Captain Arthur K. Atkins, Class of 1905, Retired 1940
Captain Hollis M. Cooley, Class of 1906, Retired 1946
Captain Claude A. Bonvillian, Class of 1906, Retired 1946
Cdr. Robert V. Lowe, Class of 1906, Retired 1930
Capt. Joseph S. Evans, Class of 1907, Retired 1947
Secretary-Treasurer of the Society 1919-1921
Capt. Philip H. Hammond, Class of 1907, Retired 1943
Capt. Edmund D. Almy, Class of 1907, Retired 1943
Capt. Baxter H. Bruce, Class of 1907, Retired 1944
Capt. Frederic T. Van Auken, Class of 1908, Retired 1946
Capt. Henry F. O. Davis, Class of 1908, Retired 1947
Secretary-Treasurer of the Society 1932
Capt. Charles C. Ross, Class of 1908, Retired 1940
Capt. David F. Ducey, Class of 1908, Retired 1947
Capt. Harry G. Donald, Class of 1908, Retired 1947
Capt. Harry B. Hird, Class of 1908, Retired 1939
Secretary-Treasurer of the Society 1927-28, 1933-34
Cdr. Karl F. Smith, Class of 1908, Retired 1932
Cdr. Leo L. Lindley, Class of 1909, Retired 1937
Captain Lybrand P. Smith, Class of 1911, Retired 1942, Died 1948
Cdr. Guysbert B. Vroom, Class of 1911, Retired 1939
Capt. Howard S. Jeans, Class of 1911, Retired 1939
Capt. Palmer H. Dunbar, Jr., Class of 1913, Retired 1943
Capt. Wilbur J. Ruble, Class of 1913, Retired 1947
Capt. Henry A. Seiller, Class of 1913, Died 1944 on active duty
Capt. William E. Malloy, Class of 1914, Retired 1949
Capt. Gerard H. Wood, Class of 1915, Retired 1946
Cdr. George K. Weber, Class of 1917, Retired 1942
Capt. Ernest B. Colton, Class of 1918, Retired 1941
Capt. Owen E. Grimm, Class of 1918, Retired 1947
Com. Harry L. Dodson, Non-N.A., Retired 1948
Capt. Roy W. Bruner, Non-N.A., Retired 1949
Capt. Duane L. Taylor, Non-N.A., Retired 1947
Capt. Roger F. McCall, Non-N.A., Retired 1947
Lt. Sidney B. Blaisdell, Non-N.A., Resigned 1922
Lt. Richard C. Bartlett, Non-N.A., Resigned 1928
Capt. Winfield A. Brooks, Class of 1919, Retired 1949
Capt. Adolph O. Gieselmann, Class of 1919, Retired 1949
Capt. James H. Chadwick, Class of 1920, Retired 1949
Capt. Benjamin P. Ward, Class of 1920, Retired 1950
Capt. James E. Hamilton, Class of 1921, Retired 1951
Secretary-Treasurer of the Society
Capt. Edward E. Roth, Class of 1921, Retired 1951

Capt. Guy Chadwick, Class of 1921, Retired 1951
Secretary-Treasurer of the Society 1938-40
Capt. Carl S. Drischler, Class of 1921, Retired 1943, Died 1944
Cdr. Joseph H. Currier, Non-N.A., Retired 1939
Capt. Marshall M. Dana, Class of 1923, Retired 1947
Captain Harry Burris, Class of 1924.

Little more can be said about the effectiveness of the legislation which was started by a brash young lieutenant because he hadn't yet learned that it doesn't pay to try to improve things.

# PART ONE

## ORIGINAL ARTICLES

The articles which the Editor, acting under the supervision of the Council, has accepted for publication in Part One are the original works of the authors.

They are offered in furtherance of the Society's raison d'etre: to further the advancement of naval engineering. Discussion of any article is invited for publication in a subsequent issue.

Permission to reprint is freely granted on condition that ***full acknowledgment is given*** to the author and to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

All articles which have been written by naval personnel or by civilian employes of the Navy Department and are published herein carry the personal view of the authors and, unless specifically so stated, do not express the official views of the Navy Department.

REAR ADMIRAL ROBERT S. GRIFFIN

Chief of the Bureau of Steam Engineering
under whom the original Engineering Duty Only group was established in 1916.

# U. S. FLEET MAINTENANCE AND BATTLE-DAMAGE REPAIRS IN THE PACIFIC DURING WORLD WAR II

CAPTAIN RALPH K. JAMES, USN

THE AUTHOR

Graduated from the U. S. Naval Academy in 1928 and in 1930 transferred to the Construction Corps. In 1933 he received an M.S. Degree from M.I.T. He subsequently served in various repairs and maintenance capacities both at Naval Shipyards and afloat, and in 1943 was the Representative Force Maintenance Officer at Espiritu Santo, responsible for coordinating all fleet repairs in that area. In 1944 he was the Maintenance Officer for Comseron Ten at Manus. In 1945 he assisted in the establishment of the Ships Parts Control Center at Mechanicsburg and served from 1946 to 1948 as Officer-in-Charge. He presently is Director of the Shipbuilding Scheduling Activity, very recently established by the Bureau of Ships in Philadelphia, Pennsylvania.

*This paper was read by Captain James at the Newcastle meeting of the International Conference of Naval Architects and Marine Engineers on 5 May, 1951. Captain James appeared at the meeting under the original sponsorship of The Society of Naval Architects and Marine Engineers. He ultimately became a representative, in addition of both the Bureau of Ships and the American Society of Naval Engineers. This paper is published as an original article in the* JOURNAL *by agreement with The Society of Naval Architects and Marine Engineers.*

*The paper is also being published in the Transactions of the North East Coast Institution of Engineers and Shipbuilders of Newcastle-upon-Tyne, England. This Society by unanimous vote of its Council awarded to Captain James the M. C. James Medal for the paper.*

ENGINEERING, *issue of August 24, 1951 had this to say on the subject:*

*"Captain James, in presenting his paper, practically ignored his printed text; but evidently he had little need of it, for he proceeded to give a summary of the paper that was so obviously the fruits of experience, and so ably delivered, that it was received with an enthusiasm rarely accorded to a paper before a professional society."*

## 1. INTRODUCTION

It is no surprise to persons associated with societies of naval architecture and marine engineering that there is a great deal more to a naval war than the actual shooting. The war in the Pacific in which the United States participated from 1941 until 1945 was no exception. At the outset of this war the United States Navy's most advanced base was situated at Pearl Harbor in the Hawaiian Islands, 2100 miles from the Pacific continental coast line. Between Pearl Harbor and the Japanese homeland lies 3300 miles of ocean dotted only by small groups of islands. Nowhere in this area were there any maintenance or logistic support facilities from which major United States Fleet units could operate. While the maintenance facilities of the Pearl Harbor Naval Shipyard were adequate for the normal Fleet activities prior to 7th December, 1941, on that fateful day the major damage done to important United States Fleet units and minor damage to shipyard facilities overwhelmed the capacity of Pearl Harbor and required returning much of this burden to the continental shipyards of the United States.

To project the military might of the allied forces westward to Japan it was necessary, therefore, to plan for and to construct advanced naval bases from which units of the Fleet could be serviced, maintained and made ready to fight again. The evolution of these advanced bases played a vital role in the success of our combined might in the Pacific. As we progressed across the Pacific, islands that were captured were converted into amphibious support bases, and in several, extensive maintenance and repair facilities were established. The first of these was at Espiritu Santo in the New Hebrides Islands of the south Pacific. The second was at Manus in the Admiralty Islands. Later in the war, an advanced base, complete with full fleet maintenance and repair facilities, was developed at Leyte-Samar. Another was in the process of development at Okinawa, and one was projected for Guam, each of which would be capable of maintaining approximately one-third of the entire Pacific Fleet. At this time the war happily concluded.

Each of these major maintenance bases was provided with adequate manpower, equipment and supplies to permit continuous routine maintenance of vessels operating in the area and to repair battle damage. Thus was executed the sound policy established by the Commander in Chief of the United States Fleet, in an effort to increase the effective size of his fighting force by eliminating the time-consuming delay of return trips to mainland bases. To quote from a report of Fleet Admiral Ernest J. King: "A base to supply or repair a fleet, five thousand miles closer to the enemy, multiplies the power which can be maintained constantly against him and greatly lessens the problems of supply and repair. The scope of the United States advanced base program is indicated by the fact that personnel assigned directly to it aggregated almost one-fifth of the entire personnel of the Navy, over half a million men."

The chart shown in Fig. 1 has been prepared to show the principal Fleet maintenance bases that existed in the Pacific at the conclusion of World War II. This chart graphically shows the tremendous saving in distances to be traveled by ships requiring maintenance and battle-damage repairs. This chart reveals that as the war progressed, the distances which these major bases were behind the active fighting front continued to diminish until the Battle of Okinawa, where development of a major fleet maintenance base progressed concurrently with the operation of seizing and securing the island itself.

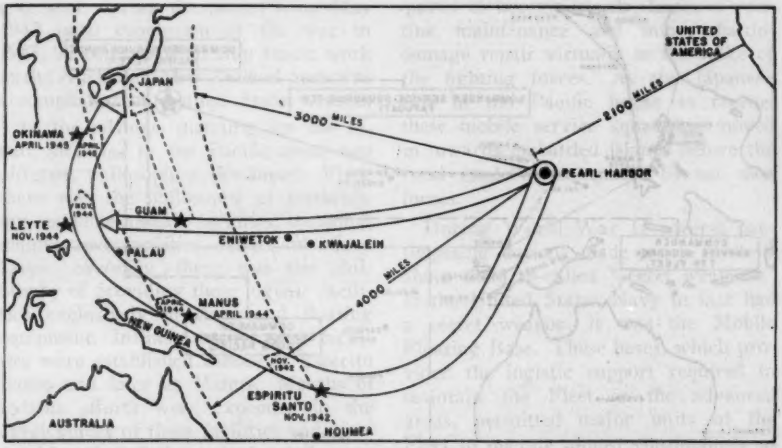


FIGURE 1—Location of Advance Bases and Pearl Harbor with respect to Principal Fleet Operating Areas. Dates under bases indicate time of establishment.

The scope of the problem of fleet maintenance and repair that confronted naval personnel in the Pacific during World War II can best be appreciated by some simple statistical information on the size of the Fleet units maintained. On December 7th, 1941, when war burst upon the Pacific, the size of the entire United States Fleet was as shown in Fig. 2. Of these, approximately 300 ships of all categories then were operating in the Pacific Ocean. The problem of maintaining these ships was comparatively simple and generally fell within the capacity of the repair facilities at Pearl Harbor and on the Pacific Coast of the United States. In August, 1945, at the end of the war, the size of the Fleet had grown tenfold. During this period the complexities and problems presented by routine maintenance and battle-damage repair grew in proportion to the improvements in design, which added many new, but complicated, equipments and installations to operating ships, creating problems that necessitated the development of special skills among the repair personnel at advanced bases.

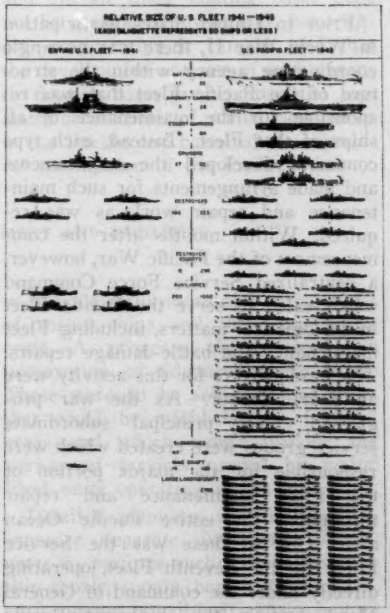

FIGURE 2—Relative Size of U. S. Fleet 1941-45. Each silhouette represents 50 ships or less

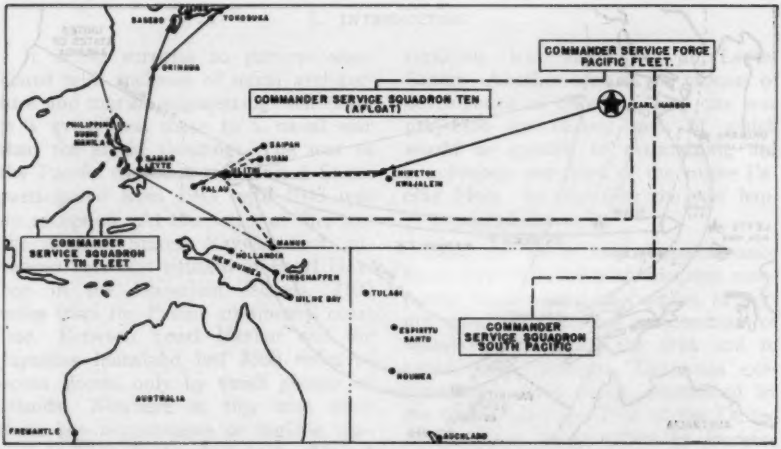


FIGURE 3—Organization and Location of Service Squadrons Pacific Fleet

### 2. PACIFIC FLEET MAINTENANCE ORGANIZATION

Prior to United States participation in World War II, there was no single coordinating agency within the structure of the Pacific Fleet that was responsible for the maintenance of all ships of that Fleet. Instead, each type command developed the requirements and made arrangements for such maintenance and repair work as was required. Within months after the commencement of the Pacific War, however, a centralized Service Force Command was created to serve the Pacific Fleet in all logistical matters, including Fleet maintenance and battle-damage repairs. The headquarters for this activity were at Pearl Harbor. As the war progressed, three principal subordinate service groups were created which were responsible for the major portion of the Fleet maintenance and repair throughout the entire Pacific Ocean area. One of these was the Service Force for the Seventh Fleet, operating directly under the command of General MacArthur in the southwest Pacific area. The second was the Service Squadron for the south Pacific area operating mostly under the command of Admiral Halsey. Finally, there was Service Squadron Ten, comprising a variety of logistic units and subdivided into many subordinate groups, all of which were completely afloat and mobile. Over all of these principal units, Commander Service Force, Pacific Fleet exercised general administrative command, determined matters of basic policy, and coordinated the material requirements of the entire Pacific with the Navy's headquarters in Washington. Fig. 3 shows essentially the maintenance and repair organization that evolved and which was in effect at the conclusion of the war in the Pacific.

It was through the organization of Commander Service Squadron, South Pacific, and Commander Service Squadron, Seventh Fleet, that liaison and coordination of maintenance and repair effort with the New Zealand and Australian Governments were conducted. Much repair, both of a routine and battle damage category, was accomplished in the shipyards in these two countries. In fact, it is interesting to

note that, during the period from May 1942 until conclusion of the war in 1945, 92 percent of all ship repair work in the Auckland, New Zealand area was accomplished on United States vessels.

In the advance planning for the repair facilities in the Pacific area, two different philosophies developed. First, there was the philosophy of establishing complete logistic facilities, including maintenance facilities, ashore on island bases. Secondly, there was the philosophy of providing these logistic facilities exclusively in ships and floating equipment. Initially major repair facilities were established ashore at Espiritu Santo and later at Manus. Months of tedious efforts were expended in the development of these facilities and after reaching their full development the war had progressed and left them behind. As a consequence of these inevitabilities, a plan was developed in 1943 to create two mobile service squadrons which would "leapfrog" each other as the war progressed towards Japan. Each of these service squadrons was to be completely mobile, and to include repair ships, tenders, supply ships, parts store ships, floating drydocks and personnel barracks; all the components required to accomplish all classes of routine maintenance and minor battle-damage repair virtually in the wake of the fighting forces. As the Japanese tide in the Pacific began to recede, these mobile service squadrons moved in towards embattled islands before the "real estate" was secured by our own forces.

During World War II several participating nations made much mystery about their so-called "secret weapons." If the United States Navy in fact had a secret weapon, it was the Mobile Floating Base. These bases, which provided the logistic support required to maintain the Fleet in the advanced areas, permitted major units of the Fleet to operate almost continuously at distances up to 1500 miles from the closest shore base. The ingenious planning and hard work required to create and operate these floating bases need not be considered mysterious, but without exaggeration it can be said that the development and use of such gigantic floating bases greatly upset the Japanese calculations of Allied capabilities in the Pacific and hastened the successful termination of the Pacific War.

### 3. MAINTENANCE EQUIPMENT AND FACILITIES

*(a) Advanced Bases*

The essentials of successful maintenance and repair is that triad of skilled men, basic materials, and suitable equipment and facilities. At the outset of World War II the United States Navy had adequate repair and maintenance facilities in the continental United States. Support of the Fleet in advance areas, however, was dependent upon a very limited number of repair ships and tenders. Prior to World War II it was appreciated that if war with Japan commenced, existing floating facilities would be completely incapable of supporting a major fleet west of Pearl Harbor. A program was instituted to provide many more and varied types of repair ships and their supporting craft. A program also evolved for preparation of advanced shore bases. These were to be self-contained units that could be established in forward areas and which would provide the variety of services needed by major Fleet units operating in the area.

Detailed planning was initiated to organize separate functional components to perform such specific tasks as ship repair, supply, harbor defense, aircraft support, small-boat repair, motor-torpedo-boat repair, major engine overhaul, landing-craft repair, minesweep-

ing equipment repair, oxygen generation and a myriad of other services. A catalogue was prepared for each of these units; specifying the required equipment including machine tools, hand tools, transport and weight-handling facilities; indicating the berthing, messing and recreational facilities required by the man-power assigned; listing the number of men, their special skills and trades that would be needed to operate these units; and tabulating the different materials required both for the subsistence of the men and for the accomplishment of the unit's assigned function.

FIGURE 4—Portion of Waterfront Area, Ship Repair Unit, Espiritu Santo

Operational planning for a specific advanced base often combined many of these separate functional components into a single advance base unit. These separate components were assembled within the United States for training of the men, the acquisition and assembly of the material and equipment and integration of the several units into a cohesive whole. When ready to move overseas, the base unit would be separated into shipping echelons so divided that in the event of loss by enemy action of several vessels, the base itself would not be unduly hampered or crippled.

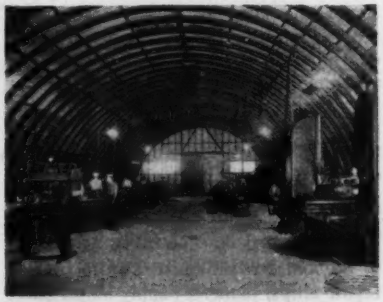

FIGURE 5—Part of Machine Shop Installation at Advance Ship Repair Unit

Typical of these advance naval-base organizations was one designated as a Lion Base, consisting roughly of 13,500 naval personnel. Primarily it was the equivalent of a small navy yard. It had within its composition a ship-repair unit capable of accomplishing repairs on any type of major naval vessel. This ship-repair unit usually was located at some convenient place on the water-front of the advance base where adequate deep-water piers could be erected (see Fig. 4). The unit itself had to be constructed on adjoining land generally carved out of the jungles. Shop buildings largely consisted of portable corrugated steel "Quonset Huts," 40 ft. by 100 ft. in size. One or more of these quonset huts comprised each of the principal shops. Requisite machine tools were erected, sometimes directly on the earth floor, but more often on concrete slabs poured for this purpose. A photograph of the interior of one of the machine-shop buildings at Espiritu Santo is shown in Fig. 5. The complete repair unit comprised a variety of shops and included such luxuries as air-conditioned instrument shops to permit delicate repair work being accomplished even in tropical climates. (See Fig. 6.) Transportation and weight-handling facilities were provided in large quantities to facilitate movement of material under repair throughout the shipyard and to and from ships at the repair piers. The complement of the ship-repair unit included skilled

FIGURE 6—Air Conditioned Instrument Shop at Advance Base Ship Repair Unit

journeymen to permit two-shift operation of its repair facilities. It further included the necessary housing, medical and recreation facilities required for subsistence of its assigned personnel for extended periods.

In addition to the ship-repair unit, the Lion Base had complete communication facilities, shore and harbor protection, hospitals, supply depots, aircraft supply and repair depots, training and recreational facilities, all in sufficient amount to support a major fleet operating in its area. It also included construction personnel required to assist in the unloading of the ships transporting the base and to construct the base after unloading. In effect it was almost completely self-sufficient.

In interesting contrast to the large Lion Base was the so-called beach repair unit. This was a highly mobile facility, designed to be carried ashore with the early assault waves attacking a beachhead. The unit generally consisted of several skid-mounted houses, complete with tools, equipment, supplies, berthing and messing facilities for its assigned crew. It was designed to make on the spot repairs to battle-damaged landing craft and to assist the beach master in removing debris from the beach. It was capable of maintaining itself under actual combat for a period of approximately four days. Fig. 7 shows one unit of the beach repair component mounted in its transporting landing craft.

*(b) Drydocks*

In addition to the shore facilities, it was essential to provide advance maintenance bases with adequate drydocks if the ship-repair units were to accomplish underwater repairs on damaged ships and routine drydocking of undamaged ships. In initial planning no consideration was given to the construction of graving docks at these bases. The long period of construction required and the high cost of these docks made such a project completely impracticable except for the permanently established bases. Full attention, therefore, was devoted to the development of floating drydock facilities, which have the inherent advantages of mobility, shorter construction time and lesser cost.

Prior to World War II the United States Navy had been experimenting with an auxiliary floating repair dock consisting of a single piece, all-steel dock with a lifting capacity of 4000 tons. This dock was ship-shaped with a closed bow and with a stern gate to form a closed docking basin. Within it were contained the required power-generating equipment, air compressors, crew's accommodation and limited shop tools that made it a self-contained minor repair unit. Its ship-shape form facili-

FIGURE 7—Beach Repair Unit for Landing Craft

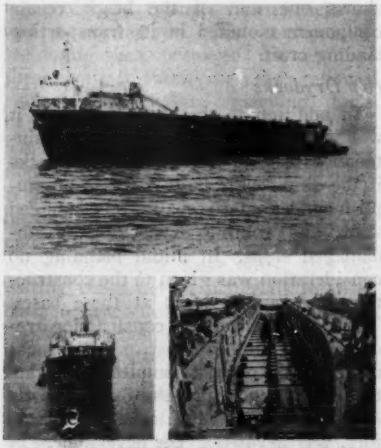

FIGURE 8—4,000-ton Floating Dry dock

tated its towing to overseas bases, and its completely closed basin made it a highly satisfactory freight carrier on its outbound trip. It carried such things as its own auxiliary storage barges, small tugs, and boats of all varieties. This particular type of drydock was designed primarily for the docking of submarines, destroyers, large landing ships and all variety of smaller craft. A large number of these docks were constructed and they soon became the work-horse of the advanced fleet-maintenance bases. In such areas as Manus there were two and sometimes three of these units continuously in use, performing routine drydocking and accomplishing battle-damage repairs to destroyers and other small craft. Fig. 8 illustrates this type of dock.

At one time in United States naval drydock planning it was contemplated constructing single-piece floating docks of sufficient capacity to handle the largest aircraft carriers then afloat. Development also was in progress on a sectional type of drydock. From these studies two types of so-called advance-base sectional drydocks evolved. The larger of these consisted of a ten-section steel dock with a combined lifting capacity of 100,000 tons, thus making it capable of lifting the heaviest vessel afloat. The smaller docks had seven units with a total lifting capacity of 56,000 tons. These were designed for drydocking heavy cruisers, small aircraft carriers and the old battleships. Each section of these docks contained its own separate power plant, its salt-water pumping systems, its compressed-air equipment, and its crew's messing and berthing facilities, so that each unit could be towed separately to the advance-base location selected. The ends of each section were faired to facilitate towing. The wing walls were hinged to allow them to lay down on the pontoon deck to give greater stability and lesser wind area during tow. Fig. 9 shows the assembled ten-section dock in use at Espiritu Santo.

Each drydock was equipped with two 15-ton-capacity cranes. While being towed these cranes were secured on the deck of a pontoon. After arrival of the several pontoon sections at the selected base area, the wing walls were raised into the vertical position by means of jacks. These sections were then sunk to deep draft and brought alongside the sections on which the cranes were carried. The tracks on the wing wall were lined up with the temporary tracks on the deck of the pontoon and the cranes moved to their normal operating position.

Another interesting feature of these drydocks was their self-docking capabilities. As drydocking of any pontoon section was required it was a relatively simple task to detach it from the main dock unit and dock it in the remaining sections. The sectionalized character of the dock further minimized the damage which would result from enemy torpedo or aerial attack.

While each pontoon section of these drydocks had its own self-contained facilities for operation of the dock, there were virtually no facilities for actual repair of ships docked. To com-

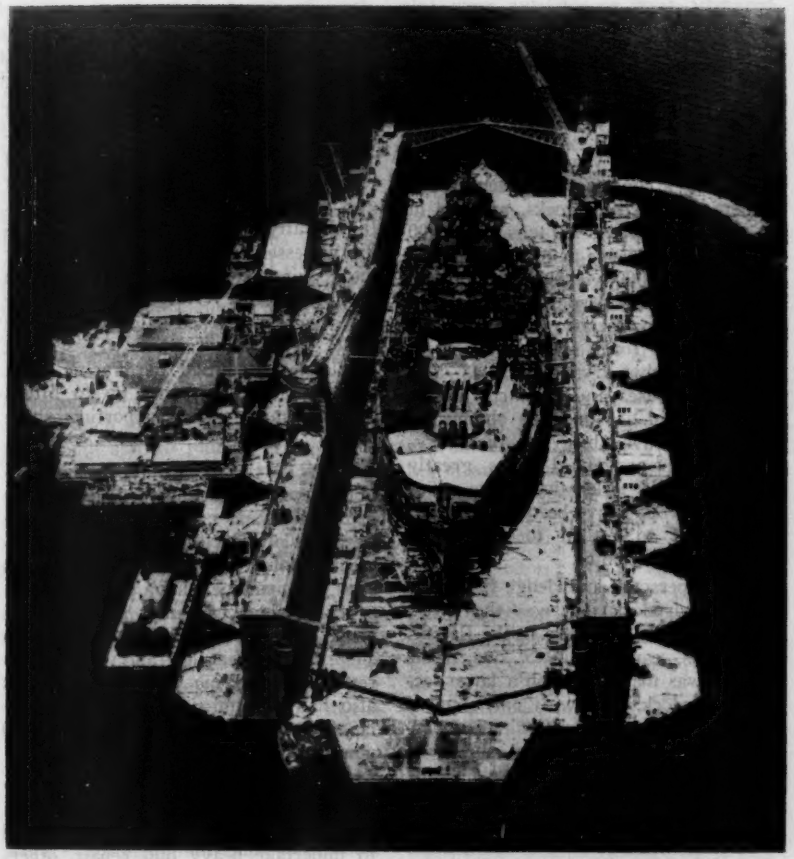

FIGURE 9—100,000-ton Advance Base Sectional Drydock in use at an Advance Base

pensate for this, two special tender barges equipped with machine tools necessary for a variety of routine repairs accompanied each drydock. These auxiliary barges were transported to the advance base aboard the pontoon sections of the dock itself. Whenever extensive repairs such as battle-damage repair were required on a ship in dock, it was the custom to bring alongside and secure to the drydock itself one or more repair ships so that their considerably greater facilities and manpower were available to undertake the repairs involved.

Due to the steel deficiencies that existed during the war, consideration also was given to the development of concrete floating docks. One such dock of 2800 tons capacity ultimately was developed and used successfully in advance base locations. Its huge walls and bulkheads were constructed of six-inch thick normal aggregate concrete. While it was considerably less efficient than the normal steel drydock in regard

to its lifting capacity in relation to its dead-weight, nevertheless it served the useful purpose of providing drydocking facilities with a minimum use of critical steel with a minimum amount of hull maintenance.

During World War II the United States Navy constructed or acquired a total of 158 floating docks, ranging in lifting capacity from 400 tons to 100,000 tons. In one twelve-month period late in the war, 7000 vessels were docked in these floating drydocks, ranging in size from motor torpedo boats to battleships of the *Iowa* class. The great majority of this drydocking was done at advance bases and primarily in the Pacific Ocean. It must be obvious to all that the availability of these drydocks in the advanced bases greatly minimized the risks that these ships otherwise would have been subjected to if required to return to continental bases for maintenance.

To my personal knowledge there was only one drydock that was the object of attack by the Japanese in the Pacific. In Manus, early in 1945, one feeble attempt was made to bomb a large sectional drydock, and with only limited success. For reasons difficult to understand, the Japanese Navy underestimated the importance of such major maintenance facilities in enhancement of fleet operating capabilities. Even at Pearl Harbor on December 7th, 1941, no attack was directed specifically at the drydocks. Had the Japanese concentrated on the maintenance facilities and drydock in advance base locations they could have seriously hampered the operations of the Pacific Fleet.

*(c) Repair Ships and Tenders*

Perhaps because the Japanese themselves had been slow in the development of fleet auxiliary support ships, they did not give full consideration to the capabilities of these vessels in supporting fleet units at great distances from major bases. It appears from a review of the records that the Japanese at no time credited the United States Navy with the capability of operating at a distance greater than a thousand miles from a major shore base. The United States Navy, however, had placed great emphasis upon the development of auxiliary ship types which would permit the fleet to operate at great distances from major shore bases. In all, fifty different varieties of auxiliary vessels were developed to meet the requirements of fleet operations in advanced areas. Over sixteen of these types were developed subsequent to the attack on Pearl Harbor. These fleet auxiliaries permitted the Pacific Fleet to range over distances up to fifteen hundred miles from supporting shore bases.

Most of the repair type ships approximated mobile shipyards of varying capabilities and capacities. They were fitted variously with a variety of equipment, tools, spare parts, and shops such as machine shop, Diesel-engine-overhaul shop, carpenter shop, electric shop, electro-plating shop, blacksmith shop, hull-plate shop and instrument-repair shop. Some of the larger ships also had medium-sized foundries capable of producing castings up to 3000 pounds.

Each different type of these repair ships was designed to perform a specialized function. Some were equipped to undertake heavy hull repair, others battle-damage repair, still others internal-combustion engine repair or landing craft and motor-torpedo-boat repair. However, when emergency dictated the need, all were capable of performing any essential work on all ship types. They generally were outfitted with spare parts, stores and supplies to service the particular specialty which they had been assigned.

Prior to the outbreak of the war, skilled journeymen assigned to these repair ships were adequate to operate all machine tools and equipment on a single-shift basis. Demands of the war,

however, increased the tempo of work and it often became necessary to utilize the machine-tool equipment twenty-four hours a day. Berthing accommodation for the operating personnel had been installed within the shop spaces in many of these ships. To permit continuous operation of shop facilities it became necessary to relocate berthing facilities to other spaces where this was possible. In many types of vessels this was not considered practicable, and new-type personnel barracks, ships and barges evolved. These provided the requisite additional berthing and messing facilities to permit the repair personnel of repair ships to have suitable accommodations. Some were converted *Liberty* ships which carried approximately 450 additional skilled journeymen. These constituted the personnel necessary to operate the repair shops on the parent ship on a full 24-hour basis.

A variety of lesser supporting types also were available at most advanced areas. These included such craft as sea-going tugs, salvage ships, small harbor tugs, some non-mobile barges for storage and issue of material, for housing of personnel, for generation of power and for distilling water. Together they comprised the floating chain that could be shifted from base to base as operations of the fleet dictated.

As previously stated, the United States Navy was increased ten-fold between 1941 and 1945. Again referring to Fig. 2, it is interesting to note that during this time the number of battleships was increased by six, the number of cruisers was increased by fifteen, and the number of aircraft carriers was increased by nineteen. In establishing a well integrated fleet, however, the number of auxiliaries was increased by 860. No better evidence can be presented of the importance of the auxiliary types in the war with Japan.

## 4. LOGISTICS SUPPORT

As previously stated, adequate fleet maintenance in the Pacific could only be achieved if the all-important triad of skilled men, proper equipment, and essential materials, was available in the proper places and at the proper time. We have discussed in some detail two phases of that triad and now I would like to touch briefly on the third, namely "essential materials." Ship-repair work is a hungry maw into which must flow a myriad of material items large and small, a variety comprehensible only to those who have actively participated in this work. In the Pacific Ocean areas, fleet maintenance material problems were divided into two basic categories. The first was the general stores materials, including steel plates and shapes, nuts, bolts and screws, rivets, welding rods, lumber, nails, paints, oils and all other essential items that required fabrication into their final form and shape. The second category was the completely prefabricated equipment and their repair parts, including such items as motors, pumps, winches, turbines, engines, and the thousands of replacement parts required to service them.

To provide the general stores material, supply depots were included in the compositions of all advance bases. The initial quantities of material to stock these depots were shipped out when the base initially was transported from the continental United States to its advanced area. These shipments, generally very comprehensive, were followed periodically by replenishment shipments of the commonly used items, attempting to anticipate the issues made at forward base areas and to provide a continuous flow from the reserve supply depots within the continental United States. These replenishments were called block shipments, and each included approximately 5000 different items of material.

This method of supply of general stores items continued throughout the early phases of the war and was reasonably satisfactory in providing the

essential material required by repair activities. Deficiencies that developed because of unexpected demands for certain items were filled by specific requests to the Continental supply services.

In addition to the shore-based supply depots, mobile floating supply support was provided by store ships, barges and other floating equipment on which these same items of maintenance material were available. These craft could be self-propelled or towed in close support of the most advanced repair echelons. Because of the time-consuming operation required to establish and fully outfit shore-based supply depots, towards the end of the war greater emphasis was placed on development of mobile supply support.

In the very earliest phases of the war, however, before material support in advanced Pacific Ocean areas was fully developed, the ingenuity of repair personnel often was taxed to the limit to improvise the materials necessary to permit the ships to be repaired and continued in service. Often captured Japanese equipment was stripped of parts and other materials for adaptation and use in the repair of United States naval vessels. One small seaplane tender which was badly damaged at the stern, thereby destroying its rudder and steering controls, was provided with a jury rudder constructed of wooden telephone poles uprooted from a Japanese communications network and fitted with steel plates removed from a Japanese bomb shelter found on the island of Tulagi in the Solomons. With this improvised rig the vessel made a successful passage from the Solomons to Pearl Harbor, a distance of over 3500 miles.

As the war progressed, however, these initial problems were overcome by the materials rolling off the production lines within the United States. In the closing months of the war the problem no longer consisted of production of materials, but rather the distribution of those materials and the maintenance of a balance between procurement and inventory. As stated in a report of Fleet Admiral King, "Motion, not size, has become the important factor."

In July of 1945 a system of uniform inventory control was established to maintain a proper balance between procurement of material and inventory. Thereafter, in lieu of receiving periodic block shipments of predetermined items and quantities, advance base supply depots instituted a uniform procedure of stock-status reporting whereby the usage of material and the quantities on hand were the essentials in determining the amounts to be resupplied. This new program permitted centralized administrative control of all materials in the Pacific Ocean area and permitted the redistribution of area excesses. This greatly facilitated the receipt of essential materials in the advanced maintenance areas from dormant stocks in areas left behind in the drive towards Japan.

A category of repair material which constituted one of the major problems of logistic support during the war was repair parts; the bits and pieces necessary to keep in continuous operation the many machines and equipment installed in naval ships. Because of their high replacement rate this was particularly true of Diesel-engine parts. Prior to the outbreak of World War II the United States Navy had only a limited number of Diesel engines in service. Most of these were installed in submarines. A few had been placed in small boats primarily for development purposes. Immediately after the outbreak of World War II, however, many new Diesel-engine applications were introduced into service to meet the demands of the accelerated shipbuilding program. Diesel engines became the main-propulsion machinery for most of the smaller ship types up to and including the destroyer escort type. So urgent was the demand upon the Diesel-engine industry for complete engine

units that very few maintenance repair parts were produced during the early part of the war. This greatly accentuated the problem of engine maintenance and repair. In November, 1944, it finally became necessary to give the manufacture of replacement parts an over-riding priority on the production lines of the United States manufacturers. The magnitude of the problem of engine-part replacements can be appreciated by recognizing that over 556 different models of engines were in operation at one time in the United States Navy. These required approximately 1½ million different parts for complete repair part support.

To shorten the lines of supply during the early phases of the war eight spare-part distribution centers were established in various geographical locations. These were located in Australia, Alaska, three in the central Pacific, on the east coast of the United States, in the British West Indies, and in England. Later in the war, because of the acquisition through lend-lease of many American Diesel engines by our Allies, it became necessary to establish spare parts distribution centers in Malta, Bombay, Canada, Russia and Brazil.

Initially the shipment of repair parts to these distribution centers was on the basis of a so-called "Automatic Flow Plan." The manufacturer of each different type of engine was requested to predict the fast-wearing parts that would be needed in his engine and to estimate the quantities of these required for support of a stated number of engines. He then was authorized to make monthly shipments of these approved quantities on an automatic basis to the many distribution centers. Unfortunately, because of the problems of material priorities, much of this automatic flow did not actually occur, and a major problem of support of Diesel-engine equipment developed in the Pacific Ocean. To alleviate this in part it became necessary to create salvage centers to which all used parts were returned for inspection, and rehabilitation for further use if practicable.

As for general stores materials, in August of 1945 the so-called automatic flow plan for resupply of Pacific spare-parts distribution centers was abandoned in favor of an integrated program of inventory control. This was based on establishment of a continental inventory control center, to coordinate the requirements of the entire fleet and to determine requirements of each advance maintenance area, based on its usage and on the fleet activity in that area. Although this program was not fully implemented prior to the end of the war, it is the basis on which fleet repair-parts support has been provided subsequent to the end of the war.

### 5. BATTLE DAMAGE

#### *(a) Battle-Damage Repairs*

In the preceding sections I have outlined the problem that existed in the Pacific Ocean area and the organization and facilities that were assembled to undertake fleet maintenance and battle-damage repairs to the Pacific Fleet. In this section I would like to discuss some of the major examples of battle-damage repair that were handled by repair personnel in the Pacific Ocean area, ones that I believe will be of general interest.

Battle-damage repairs varied in magnitude from superficial damage on small craft, to repairs of cruisers which arrived with decks awash and on the verge of capsizing. Ships with extensive damage generally were returned to the continent following completion of temporary repairs. Material was not available for major repairs, nor was it desirable to commit advance bases to rebuilding ships, thereby limiting their capacity to perform emergency repairs. Exceptions were made in some instances where work of major proportions was accomplished on vitally needed

ships such as aircraft carriers and battleships to prevent their prolonged loss to the fleet.

When temporary repairs were undertaken on ships that had received major hull damage, a complete inspection was made for evidence of structural failures as soon as possible after arrival. This included a thorough inspection by divers of the hull and all flooded compartments. Complete strength and stability calculations were made based on this inspection. Prior to docking, damaged compartments were unwatered in so far as possible after effecting limited repair by divers. Structural repairs were made so as to completely restore the original hull strength by the simplest means practicable and thus insure safe passage to the United States. Concurrently with the structural repairs, damaged machinery, particularly that which had been submerged in flooded compartments, was renovated, temporarily preserved and final tested. Except for damage which involved the loss of all propellers, ships usually returned from advance bases under their own power.

One of the most interesting types of battle damage from a structural point of view was that experienced by destroyers. Because of their small girder size, the loss of part of the hull was not an uncommon occurrence. Many destroyers lost portions of either their bow or stern, and in either situation the corrective action consisted of removing the wreckage, strengthening the remaining structure, installing a stub bow or cofferdaming the stern, and checking the stability of the remaining ship. It was then returned to continental shipyards where new sections were fabricated and installed.

The *Selfridge* is an example of a destroyer that lost its bow. She was struck by at least one, and probably two, torpedoes which completely severed seventy-five feet of the bow. (See Fig. 10.) As the bow floated aft it damaged the ship in several locations, including the starboard tail shaft, strut, and propeller. Fig. 11 shows the *Selfridge* following completion of temporary repairs with the temporary stub bow installed.

The *Abner Read* was a destroyer which lost its entire stern when the ship detonated a contact mine on her port quarter. The after seventy-five feet of the ship severed cleanly and sank within a few minutes. The port shaft was broken and sank with the stern but the starboard shaft remained intact. The starboard propeller and struts were stripped from the shaft and the shaft took a 5-degree sag following the explosion. As a consequence it was necessary to rotate the shaft 180 degrees prior to drydocking. (See Fig. 12.) After docking, the shaft was removed, a stern bulkhead was installed, and a temporary rudder was provided. After being towed to a continental shipyard the ship was docked with its new stern section and permanent repairs were completed.

Unique among destroyer repairs were those accomplished on the *Hambleton*. The *Hambleton* was damaged amidships by a submarine torpedo which left the ship in danger of breaking in half. This damage occurred during the invasion of Africa before advance bases had been established in the area. In order to save the *Hambleton* a floating drydock was salvaged and put in operating condition. Following drydocking, fifty feet of the damaged section amidships was removed. A fairing section twelve feet long was installed and the ship returned to the United States for a new fire-room and engine-room. Since the bow section had a negative metacentric height of four feet, it was necessary to ballast the bow and fasten it to the bottom of the dock while floating the stern section in position. Fig. 13 shows the area of torpedo impact and the foreshortened hull upon completion of temporary repairs.

Another type of damage was that inflicted by Kamikaze planes, which

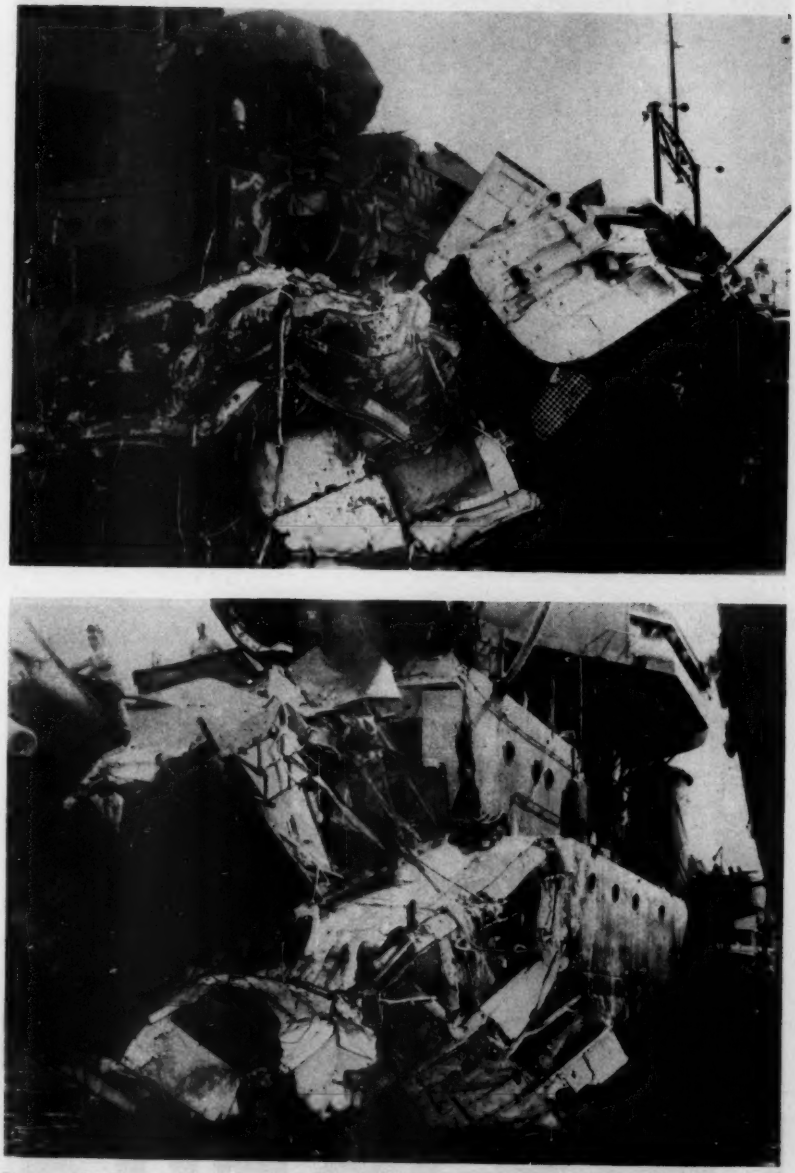

FIGURE 10—Torpedo Damage U.S.S. *Selfridge*. Views from Port and Starboard Bows

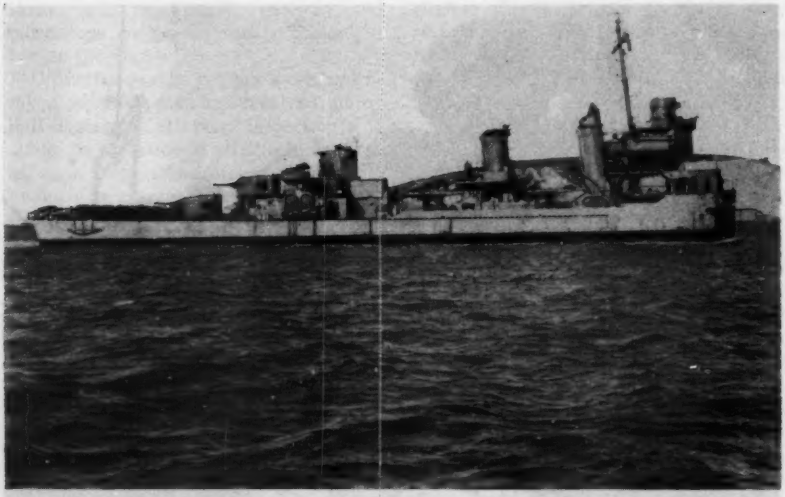

FIGURE 11—U.S.S. *Selfridge* following temporary repairs with Stub Bow installed

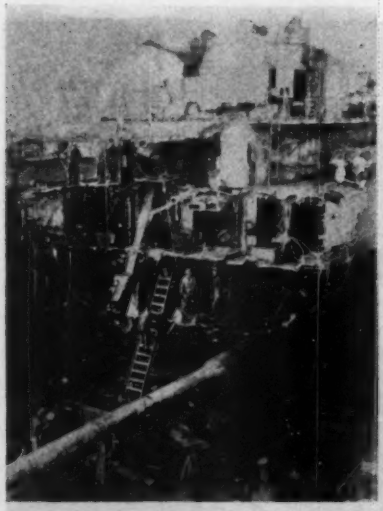

FIGURE 12—Mine Damage to U.S.S. *Abner Read,* Starboard Shaft intact although entire Stern was lost

FIGURE 14—Damage to U.S.S. *Newcomb* caused by Kamikaze Planes

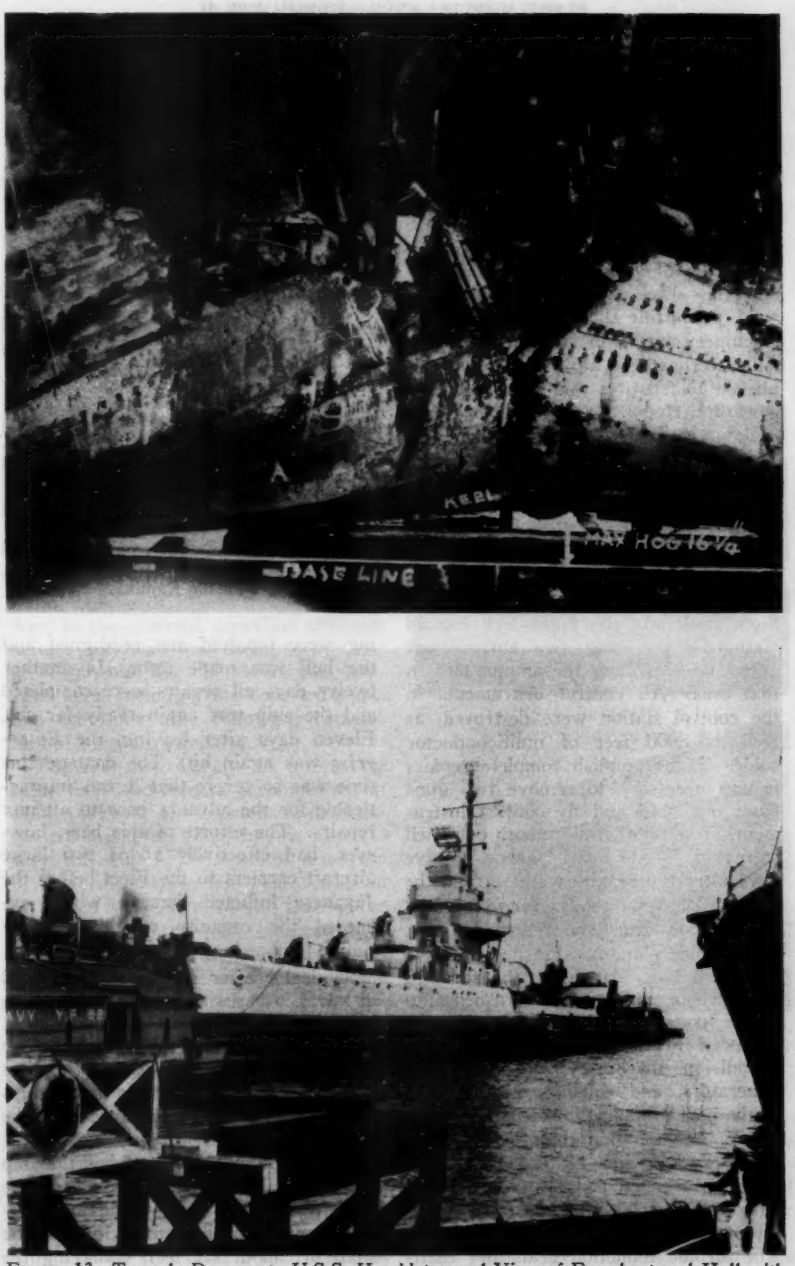


FIGURE 13—Torpedo Damage to U.S.S. *Hambleton* and View of Foreshortened Hull with one Engine-room and one Fire-room removed

were more than partial to destroyers. These attacks caused extensive topside damage and are particularly interesting because the resulting damage is what might be expected in the future from guided missiles or pilotless aircraft attacks. Fig. 14 shows the *Newcomb* following four separate hits by Kamikaze planes, one of which was carrying a bomb. In addition to the topside damage, the keel and bottom were damaged, permitting three of the four main machinery spaces to flood to the external waterline. An advance base accomplished underwater and machinery repairs and completely replaced the main deck in the damaged area. (See Fig. 15.)

The extent of repairs frequently accomplished by advance bases on large ships is typified by the experience of the USS *Enterprise,* a large aircraft carrier. A bomb had hit on the forward elevator, causing damage to the flight deck and the flight-deck control station, demolishing two anti-aircraft guns and exploding the ammunition in that area. All control instruments in the control station were destroyed, as well as 8000 feet of multiconductor cable. To accomplish complete repairs it was necessary to remove two guns from one ship and fly control instruments from another ship, both of which were returning to Pearl Harbor. Twelve days after the repairs were started, the *Enterprise* was ready for sea, and twelve days later she returned again. One suicide plane had crashed near the starboard bow, damaging the forward pump room, and another crashed into a gun sponson aft. The bomb or bombs exploded in the water, damaging the propulsion machinery and the after generators, and causing misalignment of the port propulsion shafting. Turbine chocks and the line shaft bearing feet were cracked and all reduction gear bearings were wiped on No. 3 shaft. The hull had been punctured and numerous rivet leaks were found in voids. The turbine reduction gear, and shafting were repaired and re-aligned and the hull was made tight. In another twelve days all repairs were completed and the ship was again ready for sea. Eleven days after leaving, the *Enterprise* was again hit. The damage this time was so severe that it was impracticable for the advance base to attempt repairs. The efforts of this base, however, had effectively added two large aircraft carriers to the Fleet before the Japanese inflicted damage which exceeded the capacity of this floating repair base.

FIGURE 15—Temporary Repairs to U.S.S. *Newcomb* following Kamikaze Damage

Typical cruiser repairs accomplished at advance bases are represented in the cases of the *Houston* and *Canberra.* Both ships were struck amidship by aircraft torpedoes. The damage to these ships was unique in that both ships were immobilized by one torpedo. The *Houston* was hit directly under the starboard propulsion unit when the ship was heeled 30 degrees to port, and the shaft was broken at the reduction gear-coupling. Propeller drag pulled the shaft aft about six feet, damaging the

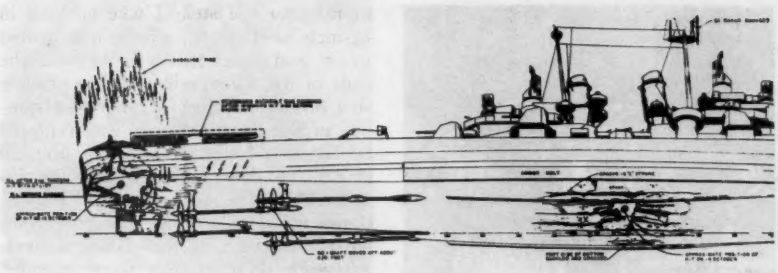

FIGURE 16—Torpedo Damage to U.S.S. *Houston*
Vessel Heeled 30° to Port

bulkhead stuffing glands. (See Fig. 16.) The forward three machinery spaces flooded from blast and fragment damage and the after engine-room flooded from the shaft damage. On the *Canberra* the torpedo struck directly under the starboard shaft, displacing it laterally and upward. This tore holes in both engine-room bulkheads, permitting them to flood to the external waterline although neither bulkhead was damaged by blast or fragment. Fig. 17 shows the damaged area, including the deflected shaft, and the same area following completion of temporary repairs.

The *Houston* damage is interesting aside from the repairs accomplished at Manus because of the extensive damage-control measures taken by the crew to save the ship. Five minutes after the first hit the metacentric height was an estimated 1.9 feet negative. During the next two days the crew removed 1600 tons of flooding water and jettisoned 120 tons of topside equipment, which restored the metacentric height to 4.5 feet positive. At this point the ship was struck by a second torpedo. Because of the corrective steps taken by the crew between torpedo hits, the second hit did not cause the loss of the ship, as it otherwise would have done. Even more remarkable were the extensive measures taken by the crew to restore some of the structural strength in way of the damaged section amidship. When structural repair materials

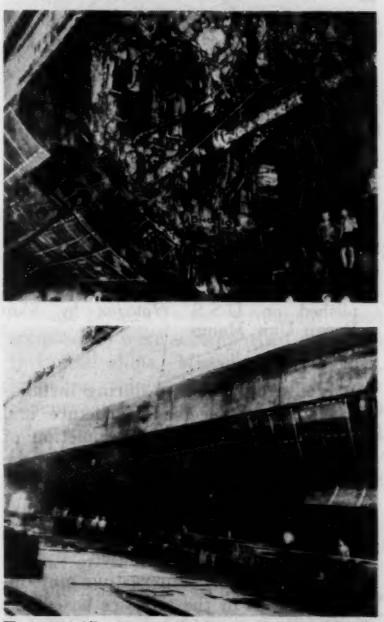

FIGURE 17—Torpedo Damage to U.S.S. *Canberra* and Completed Temporary Repairs

aboard were exhausted the crew cannibalized non-strength members to provide steel for installation in the damaged area. The repairs accomplished at Manus followed the usual pattern for complete restoration of hull strength. Fig. 18 has been included to show the

FIGURE 18—Temporary Repairs accomplished on U.S.S. *Houston* by Ship Repair Unit, Manus

damaged area amidship during installation of the replacement structure and the same area following completion of temporary repairs. Fig. 19 shows the installation of replacement transom framing. An estimated 12,000 man-days were required to complete the temporary repairs on the *Houston*.

One of the more interesting and unusual projects of the advance bases was the repair of the *Viburnium*, a 195-foot wooden hull net tender. This ship struck a contact mine on the starboard bow which shattered the hull for a length of approximately 22 feet. After the *Viburnium* was docked, debris and damaged planking were cleared away and repairs were undertaken. Since neither the materials nor trained personnel required to effect wood hull repairs were available, it was necessary to use steel. The keel was encased in ¾-inch steel plate, which was bolted to it and extended well beyond the ends of the damage in order to provide structural continuity. Transverse framing in the damaged area was replaced by fabricated steel T sections. Fig. 20 shows the damaged area and the installation of the steel structure. Fig. 21 shows the details of the resulting composite structure in the damaged area. Although these repairs were intended to enable the *Viburnium* to proceed to a mainland yard for permanent repairs, they proved so successful that the vessel continued to serve in the forward area until the end of the war. The only adverse criticism received on the work accomplished was that it was impossible to compensate the magnetic compass following these repairs.

Unfortunately the repairs accomplished in the forward area were not always as successful as those described above. Early in the war the *O'Brien*, a destroyer, was struck on the bow by a submarine torpedo. Severe flexural vibration of the hull girder followed the explosion and buckled hull plating

FIGURE 19—Temporary Repairs to Stern of U.S.S. *Houston* accomplished at Manus

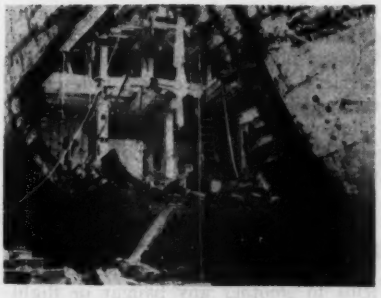

FIGURE 20—Mine Damage to Mine Layer U.S.S. *Viburnium* and Temporary Repair Measures.

and longitudinals forward and caused serious failures in the bottom structure amidship. Temporary repairs were accomplished and the ship then attempted to return to the United States. After steaming 2800 miles, the *O'Brien* broke in half and sank, although no rough weather was encountered during this time and the speed of the ship never exceeded 12½ knots. The loss of the *O'Brien* was the combined result of the lack of drydock facilities in the advance areas and the accomplishment of temporary repairs under the direction of personnel inexperienced in the details of ship construction. The loss of the *O'Brien* accelerated the advance-base program and the transfer of naval constructors to the forward areas.

These are only a few of the major

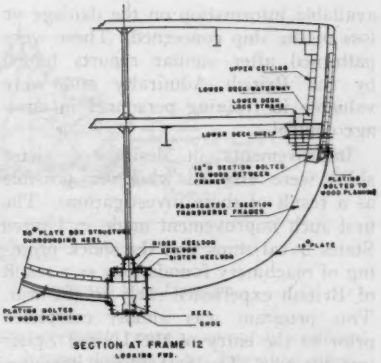


FIGURE 21—Details of Composite Structure for Steel Repairs to Wooden Hulled Net Tender U.S.S. *Viburnium*

battle-damage repair projects that were accomplished in the Pacific at forward maintenance bases. Unfortunately complete data were not kept to record the full extent of the work accomplished. Some measure of this tremendous task can be seen, however, in the statistics maintained by one principal command. In a period of one year, extensive battle-damage repairs (some permanent, some temporary) were accomplished on twenty capital ships. Miscellaneous repairs, including minor battle-damage repair concurrently was accomplished on 1800 other ships. This was all accomplished by only one of the three principal maintenance commands operating in the Pacific area.

### *(b) Design Lessons Learned as a Result of Battle Damage*

Following each case of battle damage, technical naval personnel inspected the surviving ships and interviewed survivors to analyze the damage and determine what design improvements could be made to improve the combat efficiency of these ships. When the results of these investigations were of sufficient importance to warrant their promulgation to the forces afloat, the Navy Department prepared and issued a complete War Damage Report covering all

available information on the damage or loss of the ship concerned. These were patterned after similar reports issued by the British Admiralty and were valuable in training personnel in damage control.

Improvements in design of sister ships were effected wherever possible as a result of these investigations. The first such improvement made in United States naval ships was the shock proofing of machinery foundations as a result of British experience early in the war. This program was almost completed prior to the entry of the United States into the war. The first design improvements based on United States experience followed the Pearl Harbor attack. The magazines in one ship were flooded accidentally when the magazine-flooding connections were broken by a near miss. To prevent a recurrence of this damage, magazine-flooding connections were removed from all ships and complete reliance was placed on the internal sprinkling systems.

At Pearl Harbor the inadequacy of the fire-fighting systems installed in ships was brought into sharp focus. From that fateful day throughout the remainder of the war a never-ending campaign was conducted to improve this situation. The first step taken was to remove unnecessary inflammables and to replace essential inflammables with non-inflammable substitutes wherever possible. Fire-fighting schools were established to train all shipboard personnel in the rudiments of fire fighting and to familiarize them with newly developed fire-fighting equipment. Changes were authorized to improve fire main systems, including installation of additional and larger fire pumps, some of which were located outside the main machinery spaces. Single-line fire mains were replaced with loop systems, and additional cut-out valves were installed to permit greater flexibility in operation. Improved fire-fighting equipment, including portable pumps, was developed and provided in greater quantities. Foam systems for smothering gasoline and oil fires were improved. The gasoline fire hazards on aircraft carriers were reduced by redesigning the gasoline stowage and fueling arrangements, making extensive use of inert gas for blanketing both tanks and piping. Probably the most serious fire hazard in any ship is that of fueled planes on an aircraft carrier. This problem was solved late in the war by installing remote controlled foam systems to smother any hangar or flight-deck fire. The results of these efforts to improve the fire-fighting ability of naval vessels were especially gratifying. During the first year of the war, two-thirds of all ships sunk were lost as a direct result of the uncontrolled fires started during battle. In contrast, no ships were lost for this reason in the last years of the war. The fires which resulted from a single submarine torpedo hit on the *Erie* (a 6-inch gun boat) during the first year of the war are shown in Fig. 22. These fires raged for five days and were finally extinguished by personnel and equipment sent from the United States. In contrast, Fig. 16 shows the extent of the fire experienced on the *Houston* following the torpedo hit on a gasoline tank containing 2500 gallons of gasoline. This fire was extinguished in fifteen minutes.

Another serious problem that was recognized early in the war was that of progressive flooding, and was one which caused the loss of several ships. Compartment access fittings were redesigned and some access openings were eliminated. Difficulty was experienced with flooding through all types of fittings which pierced watertight bulkheads, such as cable stuffing boxes, steam-line expansion joints, drainage lines and electric cables. Electric cables were especially troublesome because of water seeping through the core, with the consequent fire and flooding hazard at electric switchboards. The first solution to this problem was to seal the ends

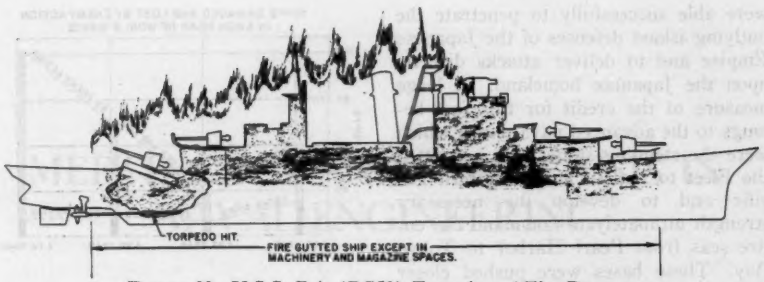


FIGURE 22—U.S.S. *Erie* (PG50) Torpedo and Fire Damage

of the cables against seepage. This solution was not completely satisfactory, so cable was redesigned to require sealing throughout the length. Finally, to assist ships in removing flooding water, permanent overboard discharge connections were installed in the hull just above the waterline.

Improvements which materially contributed to the survival of damaged ships were made in the emergency lighting and power facilities. Emergency lighting was provided by installing relay-controlled hand lanterns in vital locations to provide illumination automatically when the regular lighting system was disrupted. Even where ships were lost these lanterns resulted in a tremendous saving of lives. Emergency power for vital electrical equipment was provided by a system of permanently installed risers from switchboards with terminal boxes at vital equipments and at each watertight bulkhead. Temporary cables could then be run between risers and the equipment without impairing the ship's watertight integrity.

The above improvements are only a few examples of changes incorporated in operating ships of the Fleet as a direct result of war experience. Other improvements were necessarily confined to future designs. As described previously, the immobilization of a modern cruiser was caused by one torpedo laterally displacing the propeller shaft and rupturing the bulkheads of both engine-rooms. In the latest heavy cruisers this deficiency was corrected by separating the forward and after machinery groups by a small auxiliary machinery space and installing a complete main propulsion unit (boiler and main engine) in each main machinery space. With this arrangement it is virtually impossible for one torpedo with conventional warhead to immobilize the ship. The weakness developed in the example of the *Houston* by longitudinal movement of the propeller shaft was corrected in these ships by the installation of a single-face thrust bearing near the after end of each shaft.

The art of naval architecture is never static. From further analysis of World War II damage, and from the developments in the art of warfare that have occurred since the end of the war, we may expect to find many interesting and important changes being made to naval vessels. Obviously, however, these have no place in our present discussion.

## 6. CONCLUSION

Naturally it is the firm conviction of naval personnel that Japan was defeated because the Japanese Navy was destroyed and thereby also was destroyed the life-line upon which their armed forces depended for many vital materials and supplies. This defeat was possible because the Allied Naval forces

were able successfully to penetrate the outlying island defenses of the Japanese Empire and to deliver attacks directly upon the Japanese homeland. A large measure of the credit for this fact belongs to the advanced naval bases which were the stepping stones that permitted the Fleet to remain in the western Pacific and to develop the necessary strength ultimately to command the entire seas from Pearl Harbor to Tokyo Bay. These bases were pushed closer and closer to the fighting front until eventually in the battle of Okinawa, construction of the base was in progress as fighting for control of the island continued.

It is interesting from a technical point of view to analyze the effect of battle-damage repairs and the related ship-design improvements upon the combat efficiency of the Fleet. It has been stated that the ability of damaged ships to survive battle action is a measure of their combat efficiency. Certainly the ability of damaged ships to survive improved greatly during the four years of the war. To illustrate this, a diagram has been prepared showing the total number of ships damaged during each year of World War II as a result of enemy action, and the number of these which were lost. (See Fig. 23.) The percentage of ships lost declined rapidly as the war progressed despite the improvement in enemy weapons which the Fleet encountered, and despite the proximity of the Allied Fleet to the Japanese mainland during the last year of the war. There were several reasons for this marked decrease. Early in the war, several ships were lost because of the lack of tactical support which necessitated the sinking of damaged ships by our own forces to prevent their capture by the enemy.

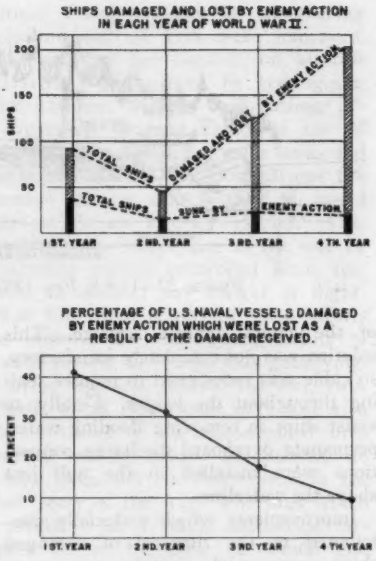


FIGURE 23

The damage control capabilities and experience of operating personnel was constantly improving as the war continued. As new ships joined the Fleet they incorporated many design and material improvements made possible by the jettisoning of the treaty restrictions under which the majority of the United States ships in service in 1941 were constructed. Probably the most important factor in the ability of ships to survive damage received in the forward area, however, was the "first aid" that was available in the advanced shore and mobile bases. Many damaged ships which undoubtedly would have been lost while trying to return to continental bases were saved because of thorough repairs accomplished by maintenance personnel in these bases.

ACKNOWLEDGMENTS

In the preparation of this paper I have collaborated with and been assisted materially by Lt. Comdr. Wayne Hoof, USN. Assistance also has been generously extended by Captain E. A. Wright, USN and Captain K. E. Romberg, USN. All photographs are U. S. Navy official photographs.

# MEETING A MANPOWER CRISIS IN NAVAL ENGINEERING

## A Documentary Account

NATHANIEL STEWART

THE AUTHOR

is not an engineer, though he would be proud to be one. MR. STEWART is a specialist in the administration of training and educational programs, and has had related management experience. Since January, 1951, he has been a member of the staff of the Industrial Relations and Manpower Division of the Bureau of Ships, with responsibilities for promoting the training of professional, scientific, and technical personnel of the U.S. Naval Shipyards and other field activities of the Bureau.

During World War II he served as Chief of Training in the U.S. Office of Censorship. For his services in training personnel in psychological and economic warfare he was awarded the Certificate of Merit.

### THE SETTING

This is the story of a mission—the mission of building a stockpile of human talent in naval engineering. It is a documentary account of the need for men with engineering savvy; specifically, how to get them, train them, and make the maximum use of their talents in the U.S. Naval Shipyards. In contrast with the depressive "ashes and sack-cloth" attitude which prevails too often in manpower circles, this account is rooted in an aggressive and constructive approach to the manpower problem.

Shortly after the outbreak of hostilities in Korea it became evident that the nation faced a scarcity in engineering skills. Observers recalled that World War II had started with scarcities in capital goods and equipment, then the shortages shifted to raw materials, and only later were scarcities in technical manpower encountered. With the Korean conflict, however, the sequence of events was different. It happened that now manpower scarcities in the engineering field hit first and hit hard, although equally vital to the shipbuilding program were the materiel shortages soon to be felt. Somebody had miscalculated, for only the summer before the engineering graduates of the Class of '50 were cautioned that the profession was "overcrowded" and that there would be only limited opportunities for engineering jobs. The big grab was now on. Survey groups now quickly spread the word that engineering college enrollments were on the decline and that, for at least a period of the next five years, the number of graduate engineers would

continue to fall short of the nation's needs in a cold war or actual conflict. While the United States requires a minimum of 20,000 graduate engineers annually to maintain the general technology of the nation, and much closer to 30,000 a year for the stepped-up demands of war and civil defense, we were faced with a dwindling supply of graduate engineers. In contrast with the 58,000 graduates in 1950, it had been predicted that the colleges and universities would yield only 32,000 in 1951, 26,000 in 1952, 17,000 in 1953, and a low of 12,000 in 1954! These data were generally substantiated in surveys by professional societies, government research groups, and the Engineering Manpower Commission of the Engineers Joint Council. Competing recruitment teams from private industry, which had secured early war contracts, were already squatting on college campuses and offering the prospective graduates attractive salaries, living quarters, bonuses, transportation expenses, and promises of rapid promotion.

Within a highly competitive setting such as described here, what was the impact upon the Navy's Bureau of Ships, one of the nation's largest industrial enterprises? A non-aggressor nation, such as ours, experiences periods of feasting and fasting in military preparedness. Military establishments were well staffed with technical personnel during World War II. Then came victory, hope for a peaceful world, demobilization, and a period of fasting. A very large number of qualified engineers, draftsmen, and technicians were released in the sharp reduction-in-force which hit the Navy. With the outbreak in Korea the Bureau of Ships was soon to discover that the accomplishment of its mission was hampered because of inadequate numbers of naval architects, and marine, electrical, mechanical, and ventilating engineers. Repair, alteration, and conversion of vessels is a complicated business, generally, and a very grim business in time of war when the supply of naval engineers is short. The competition in the heavy industries was keen and government agencies were rapidly losing technical talent to private corporations. One had only to peruse the employment bulletin boards in typical engineering colleges or to read the ads in the *New York Times* on the east coast or the *San Francisco Chronicle* on the west coast to be convinced of the acute manpower problems ahead.

Grave pronouncements from Washington do not solve a manpower crisis. There were no adequate national manpower controls over engineers; there were no "blitz" programs for intensive training of engineers, such as in World War II. There was largely talk. The Bureau of Ships was determined therefore, "to take the bull by the horns" in view of the setting described and the crisis which had to be met. It was determined to take inventory of its resources and to pave the way for building a stockpile of talent in naval engineering which would be needed for the several years to come.

## EARLY CALL TO ACTION

To set the stage for both accuracy of chronology of the story and for inclusion of leading figures in the story, it is significant to recall two important developments. First, almost at the very outbreak of conflict in Korea, a communication from the Bureau's Inspector General on the West Coast, Rear Admiral G. C. Klein, predicted the forthcoming scarcity of qualified engineers and technicians and recommended immediate attention to the problem of needed personnel in the U.S. Naval Shipyards. Alerted to the needs, the Bureau urged the Shipyards, in September 1950, to set in motion aggressive

measures to increase the numbers and the productivity of engineering and related personnel. Sharing in this leadership were Rear Admirals Clark and Dowd. In the year to follow Rear Admirals Klein and Sylvester played vital roles in keeping the problem in clear focus and in pressing for action.

There was another emerging development—the increasing evidence of leadership on the part of Commanders of the U.S. Naval Shipyards. The urgency dictated resourcefulness in the Shipyards where the local pinch was felt most severely. There were healthy signs of such resourcefulness — Shipyards turned their attention to vigorous recruitment, studied the reasons for personnel turnover in the engineering ranks, examined the backlogs of work and analyzed various management techniques by which the backlogs of design engineering work could be reduced, hired civil engineers and put them through a rotational training program leading to competency in a selected branch of naval engineering, and re-examined the potential of their Shipyard training programs. The most noteworthy step taken by the Shipyard Commanders was the encouragement of selected "blue collar" workers, familiar with the end product of design work, to move into the "white collar" ranks as supportive personnel to the professional engineers. Among these were electricians, sheetmetal layout workers, machinists, patternmakers, and workers with mold loft experience. Some of these employees had a year or two of college studies and were well grounded in mathematics and physics and needed merely some refresher courses; others were anxious to continue their studies so as to gain an understanding of engineering theory and fundamentals. At another Shipyard the emphasis was upon advanced technical education, particularly in the engineering problems relating to submarine craft. For all these encouraging signs, there was still need, however, for a comprehensive Bureau-wide program to meet the crisis in manpower for naval engineering.

## TAKING INVENTORY

To the Training Branch for Field Activities, Industrial Relations and Manpower Division of the Bureau of Ships had fallen the task of doing the spadework and preparing a blueprint for Bureau-wide action which would have the desired impact upon all U.S. Naval Shipyards. Although the Training Branch was understaffed at the time and had other major projects in progress, high priority was given to this assignment in developing a Bureau-wide program for Design Division personnel. "Operation Design" was born. Initially it was conceived that the project would be concerned primarily with naval architects and marine engineers, since these professionals were very short in supply and stood out in clear focus in the manpower picture. It was not long before it became evident that *all* related professional and sub-professional Design Division personnel would have to be incorporated: engineers in all branches; draftsmen; shop men with potential for movement into the "drafting room" environment; and, others associated with the product of design engineering.

Exploration got under way immediately. Although too detailed for full narrative here, it is well to indicate the exploratory steps taken in order to comprehend the problem fully and realistically. They may be listed in this sequence: analysis of Bureau-Shipyard correspondence on the problem; examination of job analyses and job descriptions relating to Design Division operations and personnel; study of reports of turnover of engineering personnel, the

extent and the causes; participation in high level manpower conferences in Washington; study of measures taken during World War II to meet scarcities in technical manpower; analysis of the potential strength of the Training Divisions in the Shipyards to undertake large scale training of "IVb" personnel (professional, scientific, administrative, technical, and clerical); analysis of the capacity of our colleges and universities to produce graduate engineers with potential for naval engineering duties; "corn-cob" conversations with Bureau personnel on Design Division personnel and their needs; and, finally, trips to selected U.S. Naval Shipyards on the east and west coasts, where informal conversations were held with Shipyard Commanders, Design Superintendents, Head Engineers, Training Superintendents, and others. Most significant was the scrutiny exercised in reading the trip reports of these field visits, particularly in separating the wheat from the chaff and in identifying that which was purely local and that which reflected a universal condition in Design Divisions. Headquarters analysis of the reports paved the way for isolating the bottlenecks which might impede progress in meeting this manpower crisis. So much for inventory taking.

Inevitably probing of this kind yields enough evidence by which one can begin to catalog the assets and the liabilities, the free channels and the bottlenecks, the courage and the timidity. Foremost in the minds of the Bureau officials was this question: What are the bottlenecks? In brief, the bottlenecks found may be described as follows: (1) the tendency to regard the scarcity of engineering personnel as merely a temporary condition; (2) the memory of relatively recent lay-offs of personnel and the problems of human relations involved which, obviously, made the Shipyards incline toward conservatism in hiring more engineering personnel despite the Bureau's encouragement to do more active hiring; (3) inertia in "breaking in" new Design Division employees, with the resultant loss of employee time in feeling his way around and in moving slowly toward productiveness; (4) a generally passive attitude of the Design Division toward training of personnel, probably born of tradition and because of precedent in easy procurement of graduate professional engineers from the colleges and universities; and, (5) a tendency to camouflage the real manpower utilization problem by placing blame upon the Civil Service Commission regulations governing engineers in the Federal Service and upon private industry's competition in recruiting engineers. Furthermore, training of "IVb" personnel was a relatively new frontier in Shipyard training and Design Divisions lacked the know-how of effectively organized on-the-job training of personnel. Perhaps the most restrictive bottleneck was the attitude of Design Division management that "not-a-man-can-be-spared" from the drafting board which, in effect, perpetuated the cycle of minimum performance the hard way. Not all the arguments advanced for the bottlenecks were untenable, to be sure. Backlogs of design engineering work were mounting, however, and logic was no substitute for action.

On the other side of the ledger there were very significant assets and resources—enough to negate some of the bottlenecks and to rally the forces toward a positive and aggressive fight in facing the manpower crisis. Most valued of the assets was the Bureau's fine tradition of training over the many years. Men of the various trades and crafts, artisans, draftsmen, shop foremen, and others came into occupational maturity largely because of the progressive industrial training to be found in the U.S. Naval Shipyards. A good, firm road to training had been built. There would be little likelihood of resistance to the use of this road, now, by

the professional engineers and other related technical personnel. Second, the Navy already had authority in the current Defense Appropriation Act which made funds available, if needed, for the in-service education and training of engineers, scientists, technicians, and other personnel. The Navy's Office of Industrial Relations had formulated, on the basis of this legislative authority, carefully considered provisions by which an engineer, for example, could further his own professional education when such advancement was in the interest of the Navy and national defense. Third, the Engineering Duty Officers, serving in the strategic billet of Design Superintendent, were themselves products of organized education and training—and there was little doubt but that they would be both sensitive and responsive to the need for engineering training of the civilians under their jurisdiction in order to attain maximum use of their abilities and gain maximum productivity. Fourth, in each of the U.S. Naval Shipyards there was already a nucleus of civilian professional engineers who could be counted on for germinating ideas and participating actively in raising the level of their inexperienced associate just out of college. Their role would be an important one in maintaining the standards of naval engineering. Fifth, although naval engineering is a creative profession it was recognized that in the work of design engineering in a U.S. Naval Shipyard there exist many repetitive processes, accepted sets of drawings, specifications, and orthodox procedures which lend themselves to standardization. Wherever standardization exists, even in some measure, it suggests the ease of quick training for performance of the repetitive processes involved in a job. Indeed, it also suggests tasks which are not truly professional in character and which can well be delegated to semi-technical personnel supportive of the engineers. New personnel, professional and sub-professional, could quickly be given in-service training in these phases of the work and consequently lead to early productivity.

Sixth, difficult as the manpower situation was there were still few organizations in the nation which could offer richer opportunities for professional growth than a U.S. Naval Shipyard. Many engineering specialties were there for the asking—electrical, mechanical, ordnance, marine, structural, air conditioning, heating and ventilating—and even specialties within specialties. The very scope and depth of the offerings, and the opportunity to rotate and get the "feel" of more than one branch of engineering, was in itself a recruitment lure for young engineers. Seventh, in each of the Shipyards there was to be found a wealth of instructional talent. No need to go overboard on the use of outside instructional services of neighboring colleges or universities, except where the training could be done there more economically or more effectively. The many professional engineers with years of intensive experience in naval engineering constituted a faculty that could hardly be equalled by most academic institutions. They constituted a valuable resource for any planned training program for engineering personnel. Since they were to be found in all echelons in the Design Division, they could be called upon for assistance in orientating young engineers, in instructing selected personnel in after-work courses once or twice a week, and for their part in that remarkable process of osmosis by which the disciple draws from the master. The learning process and the adaptability of graduates fresh out of engineering colleges would be accelerated. With such professionals in our ranks the shift from general to naval engineering would not be too difficult for beginning engineers.

To be sure, there were other assets and resources which were not overlooked. For example, the high quality of cooperation of the U.S. Civil Serv-

ice Commission and the Area Wage and Classification Offices; the savvy of the Training Superintendents in the U.S. Naval Shipyards; the very urgency of the manpower problem itself in a time when our nation as a member of the United Nations was at war with a calculating enemy; the good liaison relations of the Shipyards with the vocational and technical schools in their localities where refresher courses in trigonometry, blueprint reading, use of drafting instruments, etc., were available for the training of semi-technical personnel of the Design Divisions; and, finally and most forcefully, the mandate of the Bureau of Ships that we were engaged in hostilities and that ships must be repaired and altered so that they shall go to sea.

## "OPERATION DESIGN"

"Operation Design" was, quite definitely, born with benefit of clergy. It was the offspring of a union of naval engineering experts and training specialists in the Naval Shipyards. They had been courtin' for much too long a period, and it was a belated marriage, to be sure, but a very welcome one. Family support came from other officials expert in the fields of employment, wages and classification, training, aptitude testing and personnel selection, manpower utilization, engineering education, employee counseling, and management. The roster of participants which appears in the Proceedings of the Conference on Design Division Training, a recent publication of the Bureau of Ships, is a significant list of those in attendance at the baptismal rites.

"Operation Design" was comprehensive in its blueprint for recruiting, training, utilizing, and retaining naval engineers and supportive technical personnel; indeed, so comprehensive as to make any full discussion prohibitive for an issue of the JOURNAL. It would be more fitting, therefore, to marshal the cardinal principles upon which the total program was based. Each of the principles and related highlights is treated briefly in this discussion.

1. *National security.* The entire program was predicated upon the principle of national security. This was not just another training project. To regard it as such would be to commit a fundamental error. There would be no embroidery and no flowery objectives. Backlogs of design engineering work were not in the best interests of national defense and this was to be a determined effort, through training and utilization, to develop personnel who could help cut into the existing backlogs. The notion that any kind of training would be better than none was not tolerated. We were engaged in filling needs in national security, not in education padding. This was to be clearly understood by all parties.

2. *Incentives.* Adequate incentives must be provided in order to recruit and retain naval engineering personnel. In a competitive market for engineering talent, such as described earlier in this paper, it is quite costly for a Federal agency to recruit, suffer turnover or loss of personnel, and to recruit again. It would be a safe assertion that bringing a naval engineer on board reaches a cost of more than seven hundred dollars—time expended in per capita recruitment, wooing, correspondence, personnel processing, FBI loyalty investigation and ONI check, orientation in the new Design Division environment, supervisory time expended, salary until such time that the new employee becomes productive, and other items. An engineer worth recruiting should, if he has the stuff, be worth retaining. Retention success is dependent upon various factors, of course, but notably upon

the presence of incentives and job satisfaction. The naval engineer in a U.S. Naval Shipyard finds himself in a dual role—as a professional and as a Federal employee. What incentives does the new Design Division manpower program offer a young naval engineer in order to retain him? By the instrument of the Special Promotion Agreement authorized by the U.S. Civil Service Commission and detailed in the Federal Personnel Manual, first, a deserving employee can be promoted to successively better positions within reasonably short periods. Such accelerated pace is possible either in local or Bureau-wide agreements by which, through a systematic training plan for upgrading, an employee can be brought up to the point of qualifying for promotion. Another key incentive is found in the determination that more attention will be given to the matter of assigning professional duties to the professional engineer. More specifically, an effort would be made to avoid his placement at the "drafting board" for unreasonable periods of time, although it is recognized that his early months in a Design Division will necessarily involve some concentrated work at the "drafting board" as an introduction to the ways of naval architecture and engineering. The engineer's resentment at continual "drafting board" duties had long been a sore spot and a demoralizing factor, let alone a contradiction in manpower utilization.

Further incentive is lodged in the opportunities for continued engineering education if, in the judgment of the Shipyard officials, the academic work is clearly related and deemed necessary to his present or anticipated duties. Tuition at Government expense or time off for such studies, or both, when approved by the Shipyard officials are available to the selected employee at an educational institution of his choice. Incentive is further heightened because of the emergence of a sense of professionalism in the Design Division. Regardless of the background of the practitioners in the Design Division, the young naval engineer finds himself in an environment where seminars and institutes on special engineering subjects are held, distinguished lecturers are invited, membership in local engineering groups and societies is open, professional counseling is available, publication of scientific papers is encouraged, and other opportunities for professional identity exist in the emerging program. Other incentives exist, as part of the in-service training program, by which one can broaden his professional vision and attain greater competency in his current professional assignments in the Shipyard. Pre-supervisory training as a step toward preparedness for supervisory responsibilities over other naval engineers is another significant incentive. In summary, the blueprint for "Operation Design" gave major attention to the question of incentives as a vital factor in meeting the manpower crisis in naval engineering.

3. *Coverage of all echelons.* A cardinal principle in "Operation Design" is the agreement that every echelon will be exposed to the instruments by which maximum utilization of manpower is to be achieved. Incorporated into the program, therefore, were general draftsmen, draftsmen highly skilled in specialized branches, engineering aides, junior engineers, professional engineers experienced in naval engineering, naval architects, unit and section supervisors, and branch heads and others in the higher echelons of the Design Division. In addition, included in the comprehensive program were experienced mechanics, patternmakers, and other "blue collar" workers in the Shipyard interested in, qualified, and selected for technical duties in the Design Division; also, co-op students from cooperative engineering colleges, engineering students available only for summer employment, and women well qualified for performance of drafting work. From the

very outset it was clear that, if the U.S. Naval Shipyards were to accomplish their mission and reduce the backlogs of work appreciably, "Operation Design" must be concerned with the total working force of the Design Division and not merely a segment. Every pipeline of recruitment had to be opened if we were to procure professionally and technically trained personnel in sufficient numbers. While the program did not encourage frugality neither did it encourage indiscriminate or unsound tapping of recruitment sources. Each pipeline was carefully examined for its potential value as a source of manpower supply for the Design Division. Some experimental efforts in tapping these pipelines had already been carried on in the Boston, Mare Island, San Francisco, and Puget Sound Naval Shipyards—and with some measure of success.

4. *Gamut of industrial relations* A significant principle of the program was the insistence that this shall not be a token, "flash in the pan" recruitment drive. "Operation Design" called for comprehensive and sustained industrial relations — sound recruitment, well planned placement of personnel, identification of training needs and development of appropriate training programs by line supervisors, interpretation of related employment problems and liaison with the U.S. Civil Service Commission and the Area Wage and Classification Offices in the various regions, arbitration of classification questions, active counseling, monitoring of manpower utilization methods, and the use of all constructive measures in retaining the qualified and competent personnel. The Bureau was committed to assist, in staff capacity, at all possible points in this sustained industrial relations program for the Design Divisions. With the declining curve of graduate engineers from the colleges for the next five years or more, and, with continuance of hostilities which might keep this nation in a state of military tension for a number of years, it was evident that a prolonged, sustained, and active industrial relations effort would be required to meet the demands of the Navy. No one phase of personnel administration or industrial relations was to have a monopoly on the program. "Operation Design" was too big a venture to be risked by any attitude of transiency or provincialism.

5. *Multiplicity.* Significant among the principles underlying "Operation Design" was that of multiplicity. There is no single formula by which the complex problem of manpower deficiency can be solved. The manpower problem, with respect to naval engineering, had its legal, psychological, administrative, economic, military, and even historical aspects—obviously, it didn't lend itself to some easy, simple, capsule solution. Accordingly, there was need for *multiple* projects running concurrently rather than any one.

In view of the echelons to be covered in the program, "Operation Design" would entail the use of internal and external resources, formal academic courses and informal training sessions, instruction at the pre-collegiate level for the beginning draftsman to the university level for the engineer specialist, the printed word and the motion picture as media, and trial runs and seasoned efforts in training. In short, any device or project which had possibilities for training Design Division personnel economically and effectively, with minimum loss of productive time, was to be encouraged. Except for the designation of one uniform program for pre-engineering training in which the Bureau was particularly interested, the U.S. Naval Shipyards were free to release all their ingenuity, resourcefulness, and know-how in developing training programs best suited for their own on-board and new personnel in the Design Division. Inherent in this principle of multiplicity was also the principle of freedom of action. Of course, the Shipyards had to

be guided by Navy-wide policies governing employee development so that there would be no abuse of the authority granted by the Congress. One thing was paramount: every U.S. Naval Shipyard was to know the urgency of the problem as set forth by the Chief of Bureau of Ships and the responsibility it was to bear in meeting this manpower crisis. The gospel having been spread, each Shipyard was free to demonstrate what could be done to meet its needs for naval engineering manpower.

It is well to indicate, for purpose of clarity, that the multiple training efforts would fall into seven categories generally recognized: On-The-Job Training; Pre-Professional or Sub-Professional Training; Professional Development; Supervisor Development; Executive Development; After-Work Training; and, Orientation Training. Consistent with the Bureau's philosophy of training, the greater share would fall within the framework of On-The-Job Training. However, the other areas were to be exploited as fully as any Shipyard deemed necessary for its part in "Operation Design."

6. *Fusion of talent.* It was recognized that the typical Design Division is a hybrid of professional and homebred naval engineers—the latter outnumbering the former. By specifications of the U.S. Civil Service Commission both are regarded as qualified practitioners. This was no time for semantics, drawing fine distinctions of professionalism, or soul searching. The crisis called for emphasis on identity of purpose, not difference of background.

One of the guiding principles of "Operation Design," therefore, was the concept of fusion of talent, whether professionally acquired in a formal college of engineering or home-grown in the Shipyard. Each had something to learn from the other—the academic man from the veteran ship designer, and vice versa. Furthermore, the young draftsmen and junior engineers in the Design Division had something to learn from both. That Design Division thrives best where there exists this fusion of the best brainpower and seasoned experience of both types of naval engineers.

The little men and the bureaucrats prone to dismiss "Operation Design" as just another directive from Washington, the starry-eyed young officers impatient with Federal personnel regulations and practices, the Training Superintendents accustomed to a slow pace and standard timetables of employee development—none of these were to impede the over-all effort of the mission. The choice was clear: either a fusion of all available talent to meet the manpower crisis, or, rising backlogs of design work. To deny this principle would be to deny the mission.

7. *Movement.* Movement is the dynamics of any manpower utilization program. To preach optimum use of the talent of men is one thing; to make possible opportunities for such full utilization of talent is quite another thing. Movement is the essence of fulfilled opportunities. This was to be a cardinal principle of the program. Shop men, qualified and well recommended, were to have opportunity to move into the white collar ranks as draftsmen; draftsmen, having demonstrated their worth as supportive personnel and showing potential for sub-engineering duties, were to have the opportunity to move into the engineering ranks as engineering aides; engineering aides who, in the judgment of supervisors and the Design Division Training Committee show real promise as future engineers, were to be given the opportunity for movement into the professional ranks of the Division. Finally, professional engineers engaged in highly specialized assignments would, for the benefit of the Navy and for their own professional advancement, be given the opportunity to study under the nation's foremost instructors in these specialized fields of engineering.

Cumulative work experience and formal courses in engineering theory and fundamentals, for draftsmen well grounded in mathematics and physics, would qualify them as Engineering Aides. The instrumentalities: first, a Core Engineering Curriculum (the equivalent of a pre-engineering curriculum, with an option for selection of one of the recognized branches of engineering); second, a Special Promotion Agreement involving on-the-job experience and demonstrated performance of fitness. Those who had successfully completed the Core Engineering Curriculum, and were screened by the Shipyard Officials as worthy of further opportunity for advancement, could enter into a series of post-core engineering studies more closely related to professionalism and specialism. In summary, preparedness through combined experience and formal studies would engender movement, movement would generally lead to upgrading, and upgrading would yield the most in the form of maximum utilization of abilities. These were the ingredients of the principle as set forth.

One further observation: the principle was not to be viewed as an idealistic concept of personnel administration. It was to serve an end in behalf of national security. To put it bluntly in terms of manpower requirements, it could be stated in this way: half an engineer is better than none, particularly when he has completed the discipline of pre-engineering studies in mathematics and physics and is fortified with on-the-job counsel daily and with practical experience in the Design Division and on board the ships at the waterfront; before long these subprofessionals would constitute an echelon of Engineering Aides capable of rendering thousands of man-days of high level drafting and lower level engineering duties. This would relieve the professional engineers of many of the chores and would release them for the more creative and more urgent assignments more genuinely of the professional engineering kind.

8. *Coordination.* Finally, coordination of the multiple projects was accepted as one of the significant principles. Here was the typical Design Division: some 400 employees (with some of the larger U.S. Naval Shipyards having as many as 700 on board); composed of a number of units, sections, and branches; representing each of the specialties in naval engineering; employing various levels of professional, sub-professional, and technical personnel; and, encumbered with problems associated with backlogs of design work. In view of the scope, diversity, and movement, therefore, it was imperative that one key line official keep his finger on the pulse of the program.

The Bureau proposed the establishment of a new position—a Design Training Coordinator in the Design Division of the Shipyard. The Shipyards represented in the Conference on Design Division Training immediately sensed the strategic value of such a position in getting things moving quickly and effectively. The Design Training Coordinator was to be primarily an engineer, either a graduate engineer or one recognized for his practical engineering-administrative experience in a Design Division; in addition, he was to have particular competency in on-the-job training of engineers, draftsmen, and technical personnel; he was to have the personal qualities which make him readily acceptable and the requisites which command prestige in his relations with unit, section, and branch officials in the Division. Most important, he was to function as a *line* official, reporting directly to the Head Engineer and maintaining active liaison with the Design Division Training Committee and the Training Division of the Shipyard.

In light of the principle of full mobilization of industrial relations in the pro-

gram, the Design Training Coordinator would not only develop and administer the Division's training program but would also participate in the closely allied functions of recruitment, placement, and counseling of Design Division personnel. Finally, he would join the Training Superintendent in the Shipyard's liaison with local engineering colleges and universities, with specific advisory responsibilities on problems of technical content and related technical questions involved in the academic phase of "Operation Design." The responsibilities and duties of this new position were deliberately spelled out in a lengthy position-description of some nine pages, in order that there be full understanding of the incumbent's role and that the Shipyard exploit fully the potential of the position in achieving maximum utilization of the engineering and technical talent in the Design Division.

Serving in its traditional staff capacity, the regular Training Division of the Shipyard could hardly meet this crisis in naval engineering manpower. The day called for a strong "inside man" —a highly qualified engineer-educator who was directly in the interna of the Design Division and who could scout the situation daily, could identify the needs of the personnel, confer with supervisors and key officials for launching and promoting the projects, help formulate the necessary training plans, monitor the training operations, serve as a counselor for engineering and technical personnel, gauge the results, and report to the Head Engineer and the Design Superintendent the progress and problems in "Operation Design" in the particular Shipyard. The Training Division of the Shipyard would, as a staff resource, assist and reinforce the total effort wherever possible to do so.

## MEETING OF MINDS

The principles enunciated here were the products of a meeting of minds among Shipyard Commanders, Head Engineers, Training Superintendents, and Design Superintendents of the U.S. Naval Shipyards, Bureau of Ships officials, officers of the U.S. Civil Service Commission, and officials of the Navy Department's Office of Industrial Relations. The greater number of representatives, of course, were from the U.S. Naval Shipyards. The meeting of minds took place in a conference of three days, the Conference on Design Division Training, held in Washington, June 4-6, 1951.

Apart from the principles to guide the total program, other business was covered in planning the attack on several fronts. While it is not possible to reconstruct here the give-and-take during the three days of conference, it is appropriate to indicate some of the important items of the agenda and the hurdles to be cleared. At the very outset there was full and free discussion so that "line" and "staff" could resolve any differences in their concept of tackling this difficult manpower problem. Then, much attention was given to the impact of such a comprehensive program upon existing policies and practices in recruitment, position classification, salary, Civil Service Commission employment standards, etc. Attention was focused on the key personnel in the administration of "Operation Design" in a Shipyard: namely, the top management officials (Planning Officer, Design Superintendent, and the Head Engineer); the Design Training Coordinator as the "inside man"; the Training Specialist for IVb Personnel as the "outside man" for the Shipyard Training Division; and, the Design Division Training Committee. Two major questions were probed, furthermore: (a) What are the needs of the academically trained man who lacks practical experience in Design Division

work? (b) What are the needs of the practical Shipyard man who lacks academic underpinning in principles and theory in engineering? And for each—What can be done to increase their competence and productivity? Consideration was given to the identification of the needs of each group, the types of training best suited to meet the needs, the particular type of counseling required, and other pertinent matters. Other phases also commanded much attention—e.g., training to improve the competence of Design Division supervisors; work simplification programs applicable to the Design Division; training for improved writing of technical reports; and, experiences in manpower utilization.

Concern with large numbers of personnel did not blind the conferees to an equally significant question—that is, the *qualitative* aspect of performance. Increased numbers alone do not solve a problem; there must also be minimum loss through error, accuracy, completeness, and independent effort in the work performance. Particularly in the higher echelons of naval engineers was there need for specialized training and advanced education. Keeping abreast of the most recent developments in naval engineering, utilizing the products of research and experimentation, intensifying the discipline of naval engineering, avoiding any tendency to grow stale in the job—these were important elements, too, in the program. Representatives of the Portsmouth Naval Shipyard, who had done some pioneer work in plotting the course for advanced education and technical training of professional naval engineers, made significant contributions to the Conference—as did other representatives. Beyond quality of performance in naval engineering there is also the element of creativity or originality in design engineering. The Bureau of Ships, the world's largest organization concerned with ship construction, repair, alteration, and conversion, needed professional engineers who could not only perform the task of today but also to dream of the design of tomorrow. Vision, a restlessness to probe for new ways, the creative spark, deep insight into technological problems associated with design engineering—these qualities were not to be overlooked in the pursuit for greater numbers to whittle down the backlogs of work. This, too, was manpower utilization at the highest professional level.

The logistics of "Operation Design" involved, too, planning for the most scientific means of screening and sifting employees for potential upgrading, an analysis of the total numbers involved and their distribution among the U.S. Naval Shipyards, certification, supervisory follow-up, analysis of alternative plans for training draftsmen as supportive personnel to the naval engineers, and methods for recording and reporting progress and problems. The Conference on Design Division Training, which served as the pooling of experiences and views, afforded full opportunity for discussion of the logistics of these matters. Techniques for integrating parts of the program with the facilities of local colleges and universities also merited considerable analysis and discussion.

## SIGNS OF A HARVEST

Man plants a seed in the hope of reaping a harvest. The total program was envisioned as a three-year effort which would involve some 3,000 employees engaged in naval engineering, drafting, and related duties in the eleven U.S. Naval Shipyards. At this writing, only four months after the Conference meeting of minds and agreement upon principles and blueprint for action, ob-

viously, it is too early for the harvest season. Nevertheless, the men who plant the seed and till the soil are proud of early signs of growth, even long before the full harvest is in view. The purpose of the final section of this paper, therefore, is to disclose early evidences of growth—representative results of the program at this very early date.

With respect to recruitment gains, it is clear that for fiscal 1952 more than 500 persons have already been recruited since July 1, 1951—and that the aggregate figure may be closer to 850 new Design Division employees before the initial year is out. Although there has been no survey made of recruitment gains Bureau-wide, from secondary sources it has been ascertained that 100 employees have been recruited at the Puget Sound Naval Shipyard, close to 100 at the San Francisco Naval Shipyard—practically the capacity manageable with the present supervisory staff in the Shipyard—more than 100 at the Pearl Harbor Naval Shipyard, and significant numbers in other U.S. Naval Shipyards. These data relate to Design Division personnel, exclusively. Aggressive recruitment is in evidence.

Systematic and well planned orientation of new Design Division employees is now becoming universal in the Shipyards. This is a keynote of good industrial psychology and, it is hoped, the kind of first impression which goes a long way in retention of employees. New employees now have the opportunity to tour the Design Division, visit related shops, witness basic films on naval design and construction, listen to informative lectures by top echelon supervisors describing the responsibilities and work flow of their respective units, sections, and branches of the Design Division, and in other ways be exposed to the best kind of induction. The San Francisco Naval Shipyard has published a Design Information Handbook, as an instrument for orientating new employees so that they can most readily adapt themselves to new Shipyard environment. The New York Naval Shipyard is revising its series of basic lectures in the orientation program and copies are distributed to the new employees. The Portsmouth Naval Shipyard has included, in addition to its own Design Division officials, outside lecturers expert in the field of submarine craft and related fields. In addition to the orientation program proper, the Norfolk Naval Shipyard and the Philadelphia Naval Shipyard make known to the new employees opportunity for refresher courses in the after-work program of the Shipyard; other Shipyards have done this equally effectively. Commendable orientation programs, as devices for the initial effective stroke in manpower utilization, are on the rise: the ingredients include information regarding regulations and privileges in the Federal service; overview of the U.S. Naval Shipyard; intimate view of the work of a Design Division; nomenclature; and, the opportunity to meet with and listen to presentations by the most informed officials in the Shipyard.

On-the-job training, the heart of the entire Shipyard training and utilization program, constitutes approximately 90% of the total training effort. This compares very favorably with the best industrial training practices. Design Training Coordinators are actively developing on-the-job training and counseling techniques which will make the employee as productive as possible within the shortest period of time. Furthermore, "Work Methods Improvement" courses and projects are under way—there is good reason to believe that the impact will be felt in the Design Divisions and that greater emphasis upon job analysis and upon labor-saving devices will be reflected in on-the-job training.

At the professional level, too, there is much activity. During this past summer seven U.S. Naval Shipyards sent a total of 55 engineers to Massachusetts

Institute of Technology for short courses in naval architecture, marine engineering and specialized courses in servomechanisms, lubrication, corrosion, and related subjects. The Norfolk Naval Shipyard has several electronics engineers enrolled in specialized courses in neighboring universities. All of these advanced technical education projects spring from the needs and requirements of the naval activities and the individuals are selected because of their particular background, experience, current assignments, and recommendations of their supervisors.

The Core Engineering Curriculum, designed to provide an academic underpinning in pre-engineering for Design Division employees lacking such background, has been incorporated in the utilization programs of the majority of the shipyards. Contacts with more than fifteen colleges are involved in the maturation of this important phase of the program.

Active programs are under way in the Shipyards for conversion of selected engineers into Naval Architects, development of Engineering Aides (Mechanics and Hydraulics) from selected shop personnel, and training of journeymen so that they can qualify for semi-technical work in the Design Division. At the Mare Island Naval Shipyard arrangements have been made for a comprehensive training program for engineering personnel, including the core and post-core courses to be offered through the facilities of the University of California and Vallejo College. Prior to "Operation Design," to be sure, the Mare Island Naval Shipyard had made original and significant advances in meeting the manpower problem. The Norfolk Naval Shipyard has embarked upon a clearly stated and well conceived program for the use of "co-op" students from four engineering colleges. This is a pioneer effort on the part of the Norfolk Naval Shipyard and one which has won the commendation of the Bureau and of the U.S. Civil Service Commission. It demonstrates unusual resourcefulness in tapping available pipelines of supply of engineering talent. The Bureau's Industrial Relations and Manpower Division has completed several significant surveys designed to correlate data which serve as valuable raw material in assisting the U.S. Naval Shipyards in matters of employment, testing, and classification.

There is an abundance of fertility of thinking and capacity for vigorous action, as demonstrated, in the U.S. Naval Shipyards. They are meeting the crisis head-on in a sound, vigorous, and far-reaching manner. This is only the beginning.

In essence, this is the documentary account of how the U.S. Naval Shipyards attempted to meet a manpower crisis in naval engineering. It is hoped that in due time an equally exciting documentary will be written of the actual results and achievements. The acid test is yet to come—the determination of whether the added manpower and the utilization of the talent will yield the desired results. There is good reason to believe that the U.S. Naval Shipyards will meet the test.

# A STATISTICAL APPROACH TO THE STUDY OF SHIP MOTION

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SUMMARY

This report introduces a statistical method of handling complex experimental data into the field of Naval Architecture. The method, multiple factor analysis, is a form of dimensional analysis, and is strictly a mathematical study of the experimental results to find overall relationships between groups of variables. It is a logical tool that can present very complex information in such a form that interpretation of the information is appreciably assisted. This report uses data obtained in seaway simulation tests performed by a self-propelled oil tanker model (TMB No. 4057) at the U. S. Naval Experimental Model Basin.[1*]

The three objects of the report are as follows:

(a) To present the method, together with its major objects, assumptions, and limitations;

(b) To present a few results of attack of the seaway simulation test data as examples of the method's use. It should be noted that the intent was to illustrate the method. For this reason, the factor analysis was not carried to completion beyond these aims;

(c) To describe procedures used in obtaining these results in sufficient detail to provide an insight into the mechanics of its operation. In view of the nature of the method, a brief mathematical text is included to assist in its understanding.

* All numbered references will be found on pages 829 and 830.

## STATISTICAL STUDY

### OUTLINE OF RESULTS

As noted in the summary, this report is intended to illustrate the multiple factor method.[2] The illustrative uses of the method are as follows:

(a) Resonant pitch oscillation of the model was confirmed in a large number of test runs;

(b) For resonant pitching, the period of the pitch divided by the period of wave encounter tended to be one of the simple ratios 1/2, 1/1, 3/2;

(c) After accounting for the effects of displacement on pitch and heave behavior from still water standardizing runs, the effects of displacement under simulated seaway conditions were almost entirely accounted for by a simple relation found to exist between displacement, average pitch angle and velocity of encounter;[3]

(d) The maximum observed angular velocities of pitching are associated with thrust values a little higher than those required for corresponding model velocities in still water. Very high thrust values are associated with somewhat lower maximum pitching angular velocities;

(e) Measurement of the several time periods used in this (periods of wave oscillation, of wave encounter, of pitching or of heaving) is relatively difficult. A measure of the relative unreliability of these values has been obtained from this preliminary analysis, subject to a few simplifying assumptions;

(f) Still water test runs were used for calibration of the model for pitch, heave and thrust. It has been found that the model velocity has very little relation to the other experimental variables after accounting for these still water effects. The velocity of wave encounter is the effective measure of seaway response after such calibration. This result is in accordance with the intuitive concept of the independence of wave and overall water motions relative to the model in production of pitching and heaving.

### CONCLUSIONS AND RECOMMENDATIONS

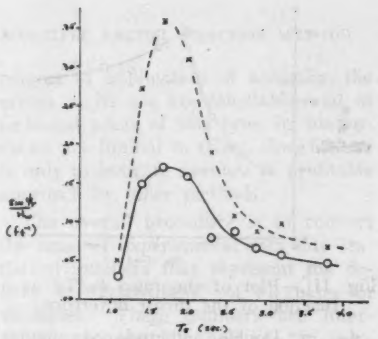
The results outlined in the previous section indicate the range of information available from a factorial study of a series of experiments. Several of these items (Results (c), (e), and (f)) are very difficult to find by other methods. In addition, since the experimental data is handled en masse, it is possible to draw conclusions that are relatively independent of any particular set of experimental conditions that may confuse a test-by-test standard means of approach.

Let us take certain resonant response data as an example. For model TMB No. 4030, six runs that showed the largest values of pitching amplitude were plotted for pitch as a function of time. One such plot was made for model No. 4057. This number of model runs is scarcely sufficient to confirm or refute the hypothesis of resonant response. Result (a) of the previous section is based on Figure I, which is a plot of all of the test data for model No. 4057, 114 runs. This quantity of data is relatively reliable. Since it is taken directly from the experimental results without curve fairing or other intermediate steps of approximation, it enables a sound conclusion to be made.

However, multiple factor analysis does not provide a complete answer in itself. It is only a means of isolating groups of closely related variables from a very heterogeneous mass of information. As a means of pointing towards fruitful combinations of variables, it is effective. The efficiency of the use made of this knowledge will depend on the subsequent analytical procedure. Also, since the procedure operates on the sum total of the table of data that represents the experiments, it will be found that some of the relationships pointed out by the method will already be suspected or known.

Under "Mathematical Background" (page 818) it is noted that an assumption of linearly weighted factor loadings underlies this whole procedure. On face value, this assumption might be interpreted to mean an extremely severe limitation on its efficiency. However, examination of Figures I, II, III, and V explanatory of Results (a), (b), (c), and (d), above shows an extremely wide variation in algebraic type of relationship pointed out. This is an example of wide utility of the method.

It may be concluded that this type of multiple factor analysis is an appropriate preliminary tool in at least this phase of Naval Architecture. Although the data have not been analyzed to completion, the power and versatility of the analysis have been indicated. It is therefore recommended that the completion and extension of the analysis be carried out as indicated in the last part of the Section entitled "Results." This completion and extension includes the following:



x = Maximum values.
O = Mean values.*

Fig. I.—Plot of the function $\frac{\text{Sin } \psi_T}{H_w}$ as a function of the period of wave encounter.
$\psi_T$ = Double amplitude of angular oscillation in pitch.
$H_w$ = Wave height.
$T_e$ = Period of wave encounter.

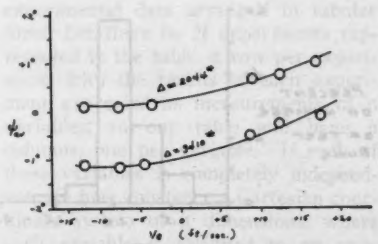


Fig. II.—Relation between diisplacement, average pitch angle and velocity of encounter—uncorrected $\psi_{av}$ values (see Fig. VI for corrected $\psi_{av}$ values).
$\Delta$ = Model displacement.
$\psi_{av}$ = Average pitch angle.
$V_e$ = Velocity of wave encounter.

* These are the mean values for the $\frac{\text{Sin } \psi_T}{H_w}$, s for all the model runs whose $T_e$ values are within the indicated 0.3 second ranges (i.e., the mean $\frac{\text{Sin } \psi_T}{H_w}$ value for the 29 model runs with $T_e$ of 1.6 to 1.8 sec., inclusive, is 0.16).

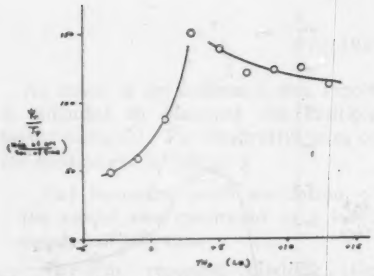


Fig. III.—Plot of the ratio $\psi_T/T\psi$ as a function of the thrust difference.

$\psi_T$ = Double amplitude of angular oscillation in pitch.
$T\psi$ = Period of pitching.
$TH_D$ = Thrust difference (i.e., thrust less corresponding still-water thrust).

(a) Expansion of the data to include that of model TMB No. 4030;

(b) Revision of the list of considered variables to overcome the ambiguity in signs;

(c) Trial of the model 4030 data to confirm the relations already observed for model No. 4057, and, if this is the case, abridgement of the variable list to delete these effects from the examination;

(d) Addition of new variables to extend the range of the analysis;

(e) Full exposition of the factorial structure of the revised and expanded data field, complete with the subsequent analysis of the class of relationship involved.

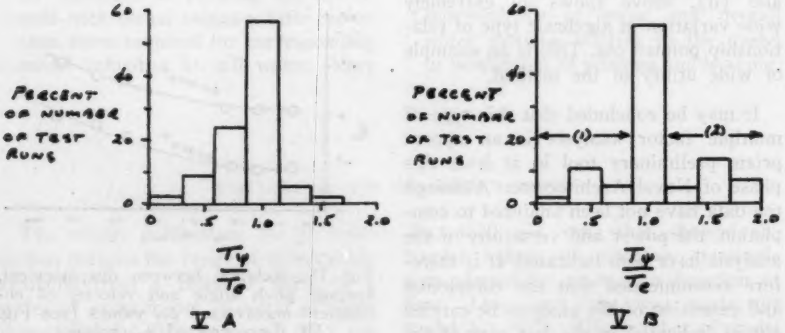



Fig. V.—Distribution of the test runs by the ratio of the period of pitching to the period of wave encounter. Plotted separately for high and low $\frac{\text{Sin } \psi_T}{H_w}$ values.

(1) Mean $\frac{T\psi}{T_e}$ ratio for these runs is 0.5.

(2) Mean $\frac{T\psi}{T_e}$ ratio for these runs is 1.6.

## INTRODUCTION AND DISCUSSION OF THE MULTIPLE FACTOR ANALYSIS METHOD

In the field of a "pure science" it is possible to plan an experiment or series of experiments to confirm or refute a particular hypothesis. It is possible to construct experimental systems where all but one variable, or at most, a very few variables, are held constant. Interpretation is a matter of comparing the results with the calculated effects. This class of procedure implies complete knowledge of interrelations between the experimental variables and a high order of control of all the experimental conditions.

The above implications are not satisfied by a wide range of sciences. In some cases, the number of variables is too large to enable one-by-one manipulation to be used as a means of experimental procedure. It would require too long a time and would be too expensive for justification. In some other cases, the theoretical background is not secure enough to enable certain calculation. In such cases, auxiliary logical tools are required to overcome the limitations of the traditional experimental procedure.

These auxiliary logical tools may be subjective, based upon long experience in the field, or objective, and may involve procedures for manipulation of the experimental results to attain intelligibility. In either case, the major questions that must be answered for use of such an auxiliary tool are "is it efficient in its use of the available data," and "does it imply more accuracy than it actually possesses."

The form of multiple factor analysis presented in this Article is an objective auxiliary logical tool. Since it is statistical in nature, its efficiency in use of data can be calculated. As a matter of interest, it cannot compete with the efficiency of the traditional interpretive procedures until the number of variables concerned are large in number (let us say, on the order of 10 or more). With respect to implication of accuracy, the errors in its use are calculable, and in technical areas of this type, its inaccuracies are limited in effect, since its use is only to indicate avenues of profitable approach by other methods.

The overall procedure is to convert the mass of experimental data into statistical numbers that represent the degree of "relatedness" of all pairs of variables. These numbers are interpreted geometrically and are, in turn, manipulated to achieve a geometric picture of the "relatedness" of the variables in groups. The original data is then re-used to disclose the class of relationship that is involved in these groups of variables. Traditional methods, such as graphical procedures, are convenient for the purpose.

The logic of this form of multiple factor analysis may be explained by reference to a hypothetical series of experiments. Let us visualize a mass of experimental data arranged in tabular form. Let there be N experiments represented in the table, a row per experiment, with the results of each experiment expressed as measurements of n variables, so our table will have n columns, one per variable. If each of these variables is completely independent, we may construct a Cartesian coordinate system of n dimensions, where each variable is assigned to an axis. We may then represent the table of data by N points in this n-dimensional space, where each point is defined by its n projections on the coordinate axes. The table of data and the n-dimensional plot are completely equivalent.

Now if one of these variables, let us say variable "a," is really a function of some other variables, let us say "b," "c," and "d," then except as a check on experimental errors, column "a" adds no data to the table. The "a" values may be calculated from the "b," "c," and "d" values. Therefore, we may

express the set of experiments in n-1 columns, or the corresponding plot in n-1 dimensions. Thus, interdependence of the variables is reflected in a decrease in the number of variables or dimensions required for expression of the experimental results, where those experimental results are expressed only to the accuracy implied by the errors in measurement.

Let us assume that we have such a table and plot, and that we have "f" columns and axes, respectively, to represent the experimental data, where "f" is equal to or less than n. If we were to rotate one or more of the axes to a new position, and leave the N data points untouched, we would still have an accurate description of the experiments. The relative positions of the points rather than a particular set of numerical values represents the information gained by the experiments. The same could be said of the new f-columned table, created from the old one by an operation equivalent to the rotation of axes.

We may express each experiment in terms of the original n variables as well as by such an arbitrary set of mutually right angled axes. This follows from the original description of the f axes, since we may say that each of the n variables may be represented by one of the axes or by a line determined by two or more axes. Therefore, we should be able to draw a new set of n lines in the f-dimensional space, where each line represents one of the original variables. These lines would be fixed by the N data points, regardless of the orientation of the arbitrary coordinate axes used to describe them for a particular plot.

Thurstone's procedure supplies a means of finding the relative positions of such a set of n "variable representing" lines in this f-dimensional space.[4] He shows that the angular separation of these lines is a function of the "relatedness" of the variables concerned, and may be used to isolate groups of variables that are connected in the set of N experiments. With this group isolation, we may return to the original data for investigation of the cause of connectivity. It was from groups of variables isolated in this manner that the relations were found that were reported under "Outline of Results."

## RESULTS

(A) *Table of Definitions:*

(1) Pitch—Used as a relative measure in comparing still water and simulated seaway model response. It is defined as the difference between the angle from the load water plane to the horizontal during a test run and the corresponding angle found at the same model velocity in still water. The pitch angle is called positive when the bow is higher than the stern.

(2) Heave—Defined as the difference between the vertical distance from the mean sea level to the center of gravity of the model during a test run and the corresponding distance at the same model velocity in still water. The heave is called positive when the center of gravity is higher during the test run than during the still water run, relative to the mean sea level.

(3) Model Velocity — Is measured relative to the tank, with signs chosen so as to make it always positive.

(4) Wave Height—Vertical crest to trough distance. Regarded as positive in all cases.

(5) Wave Length—Horizontal crest-to-crest or trough-to-trough distance. Regarded as positive in all cases.

(6) Wave Velocity — Is measured relative to the tank, with signs chosen in accordance with the assignment of a positive sign to the model velocity (i.e.,

in a following sea, the wave velocity is given a positive sign).

(7) Velocity of Encounter—Algebraic sum of model velocity and wave velocity.

(8) Period of Pitch, Heave, Wave, Wave Encounter—The time periods for one complete cycle of pitching response, heaving motion, wave form relative to a fixed point on the tank and wave form on a fixed point on the model, respectively. All periods are regarded as positive.

(9) Displacement—Weight of water displaced by the model under the conditions of test.

(10) Thrust—The value reported by the optical dynamometer in the self-propelled model.

(11) Thrust Difference—The thrust under conditions of test less the thrust for the corresponding still water model velocity.

(B) *Symbols Used:*

A subscript system is used. The large symbols $\psi$, Z, V, $\lambda$ H, T, $\Delta$ TH, indicate, respectively, pitch angle, heave distance, velocity, wave length, wave height, period, displacement and thrust. The subscripts "w," "m," and "e" are used for distinguishing between velocities of the waves, of the model and of encounter. The subscripts "T" and "av" are used to indicate double amplitude and average pitch and heave.[5] The subscript "w" is used with H to indicate wave height. The subscripts "$\psi$," "Z," "w," and "e" are used with T to indicate the respective periods of pitch, heave, waves and wave encounter. $\Delta$ is used without subscript. The subscript "d" is used with TH to indicate thrust difference.

(C) *Direct Results:*

(1) Demonstration of Resonant Response in Pitch. Resonant oscillation in pitch was suspected from model behavior in a few of the test runs, and a series of graphs were prepared to demonstrate a few outstanding examples for model numbers 4057 and 4030. In order to confirm this suspicion, it would be necessary to show that resonant response was a general phenomenon of model behavior.

The factorial method would be suitable for such a demonstration, if an index of resonant response were included among the items descriptive of the model behavior during the tests. The function $(\text{Sin } \psi_T)/H_w$ was used as such an index. In this particular case, $(\text{Sin } \psi_T)/H_w$ is factorially equivalent to $Rg(\text{Sin } \psi_T)/H_w$,[6] which is a measure of the efficiency of oscillatory energy transfer from the waves to the model.

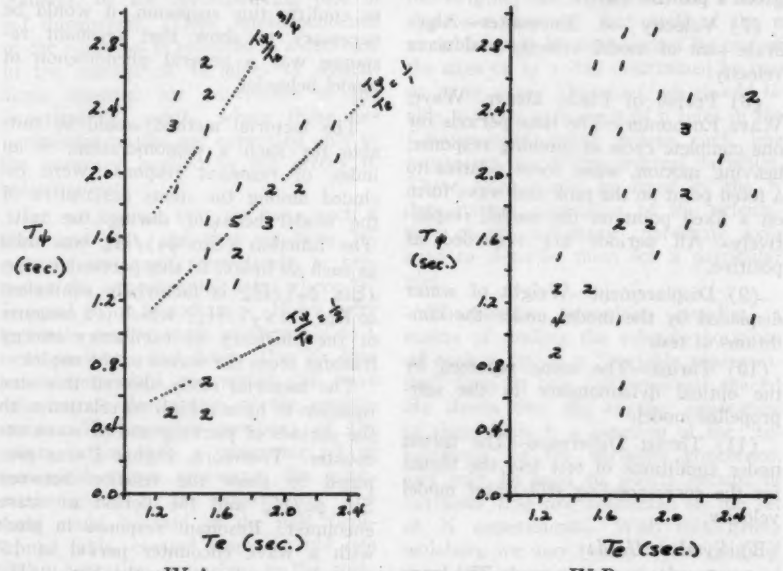
The factorial study showed this sine function to have a high correlation with the periods of pitching and of wave encounter. Therefore, Figure I was prepared to show the relation between $\text{Sin } \psi_T/H_w$ and the period of wave encounter. Resonant response in pitch with a wave encounter period of 1.7 seconds, is indicated by the $\text{Sin } \psi_T/H_w$ values plotted as a function of wave encounter period. Since this mean curve represents all the experimental data, we may conclude that resonant pitch response is demonstrated by model 4057.

A further confirmation is provided by the curve of maximum $\text{Sin } \psi_T/H_w$ values as a function of period or encounter, also shown in Figure I. The maxima represented apparently indicate runs where the other experimental variables have permitted a larger pitch response of the model. It may be seen that the curve of maxima is of the same type as that of the means, and that it also indicates resonant response in the vicinity of 1.7 seconds for the period of wave encounter.

(2) *Periods of Pitching and Wave Encounter:*

The third of the variables involved in resonant response is the period of pitching. Using the runs whose periods of

Sample: The "2" in Fig. IV-A between $T\psi = 2.4$ and $T\psi = 2.6$ and $T_e = 1.4$ and $T_e = 1.6$ indicates that two model runs were reported within these limits.




IV-A. IV-B.

$\frac{\text{Sin } \psi_T}{H_w}$ values above mean line in Fig. I. $\frac{\text{Sin } \psi_T}{H_w}$ values below mean line in Fig. I.

Fig. IV.—Number of test runs, grouped by period of pitch and period of encounter ranges, in the resonant region of Fig. I (i.e., $1.2 \leq T_e \leq 2.5$ in Fig. I). Plotted separately for test runs above and below the mean line in Fig. I.

$T\psi$ = Period of pitching.
$T_e$ = Period of wave encounter.

encounter were 1.2 seconds to 2.5 seconds (the region of high sine function values in Figure I), the model runs were separated into two groups. The first group contained those model runs whose sine function values were above the mean line of Figure I (i.e., those runs exhibiting the greatest resonant pitching response). The second group contained those runs whose sine function values were below the mean line of Figure I (those runs with least resonant pitching at wave encounter periods near resonance). Figure IV-A is a plot of the distribution of the periods of pitching and of wave encounter for the first group, and Figure IV-B is the corresponding plot for the second group. As indicated by the lines drawn in Figure IV-A, it may be seen that the "most resonant" runs appear to be clustered in three groups. These groups have periods of pitching about 1/2, about the same, and about 3/2 the period of wave encounter. The "least resonant" runs of Figure IV-B show a tendency towards the same distribution, but in a much more diffuse manner.

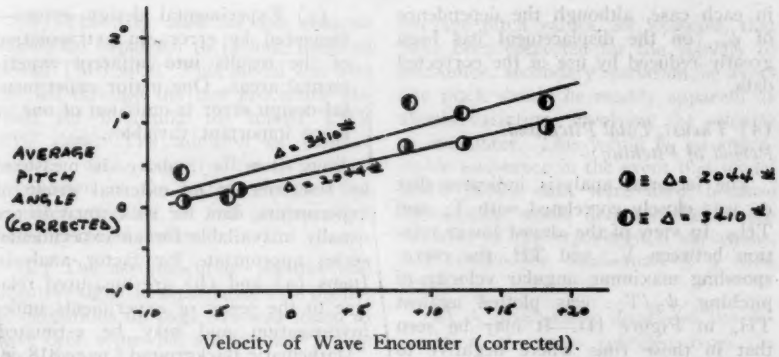



Fig. VI.—Relation between displacement, average pitch angle and velocity of encounter —corrected * values of $V_e$ and $\psi_{av.}$

* $V_e$ has been corrected for a minor change in $V_w$ that was consequent from the testing tank description and the location of the model in the tank at the time of reporting the experimental values. $\psi_{av}$ has been corrected for the squat angle error noted in the text.

Figure V was prepared to examine this relation in more detail, over the range of all of the models runs. From Figure I, the value of 0.08 or lower for Sin $\psi_T/H_w$ was taken as an indication of low efficiency in transfer of oscillatory energy from the waves to produce pitching of the model.

Figure V-A shows the model runs with low sine function values, and indicates the percentage of runs with $T\psi/T_e$ values in the indicated ranges (i.e., almost 60% of the runs concerned had $T\psi/T_e$ ratios between 0.8 and 1.2). Figure V-B shows the corresponding distribution for the runs with high sine function values. It may be seen that the group of high sine function model runs has a very definite tendency towards $T\psi/T_e$ ratios of 1/2, 1/1, and 3/2, and that the low sine function runs do not have this tendency. The "diffuseness" of the Figure IV-B distribution is shown, by Figures V-A and V-B, to be associated with non-resonant conditions dictated by the other variables in the series of model test runs.

(3) *Displacement and Average Pitch:*

High correlation of $\Delta$ with $\psi_{av.}$ was observed, with slight correlation of the two with $V_e$. After this analysis was well started, a systematic error in $\psi_{av.}$ values was discovered, that would invert the sign of a pitch correction for head and following seas.

Rather than recalculate the whole system, it was decided to continue the analysis using the erroneous data, on the grounds that the method would still operate accurately on variables unrelated to $\psi_{av.}$, and subsequently to correct any relations which showed involvement of $\psi_{av.}$. Figure II is a plot of $\psi_{av.}$ against $V_e$ for the two displacement values for the uncorrected $\psi_{av.}$ values. Figure VI is the corresponding plot after correction.

It may be seen that in both cases there is a simple relation between the mean values of $\psi_{av.}$ for a given $V_e$ range for a given displacement and the $V_e$ mean range value. The mean lines that represent the heavy and light displacements are approximately parallel

in each case, although the dependence of $\psi_{av.}$ on the displacement has been greatly reduced by use of the corrected data.

(4) *Thrust, Total Pitch and Period of Pitching:*

The factorial analysis indicates that $\psi_T$ was closely correlated with $T_\psi$ and $TH_d$. In view of the almost linear relation between $V_m$ and TH, the corresponding maximum angular velocity of pitching, $\psi_T/T_\psi$, was plotted against $TH_d$ in Figure III. It may be seen that in those runs where negative to very low positive $TH_d$ values were reported, the associated $\psi_T/T_\psi$ values tended to be quite low, rising to a peak in the vicinity of $TH_d = 3$ lbs. From this peak the $\psi_T/T_\psi$ values slowly drop to the limits of the experimental data. It may not be ascertained from this information that $\psi_T/T_\psi$ is the primary variable concerned. The basic relationship could be that of an energy of oscillation, or some other function of $\psi_T$ and $T_\psi$. However, the overall picture is striking in that the highest angular velocities of pitching are associated with low but positive additional thrust requirements of the model.

(5) *Independence of Variables:*

The precision of measurement in a group of experiments may be considered to be a function of three general classes of errors. These are:

(a) Instrumental errors—measured by differences in experimental values on repetition of the experiments.

(b) Equipment errors — measured by differences in experimental values on repetition of the experiments, where the experimental values have been corrected for item (a), above, and where different devices are used to report the experimental variables. Equipment errors are functions of the peculiarities of the particular procedures or pieces of experimental equipment.

(c) Experimental design errors—measured by errors in extrapolation of the results into adjacent experimental areas. One major experimental design error is omission of one or more important variables.

Since item (c), above, is measured by reference to an external group of experiments, data for its estimation are usually unavailable for an experimental series appropriate for factor analysis. Items (a) and (b) are measured relative to the series of experiments under investigation and may be estimated. "Mathematic Background," page 818, indicates the calculation of a number for each experimental variable that is an index of items (a) and (b). This index is the fraction of the variation in a given variable that is independent of all of the other variables used to describe the series of experiments. This fraction is about 0.5 for the four time measurements ($T_w$, $T_e$, $T_\psi$, and $T_z$), almost 1 for $V_m$ and about 0.9 for $TH_d$.

The variance in the time measurements confirms the relatively high instrumental error reported subjectively elsewhere. The high variance in $V_m$ measurements indicates that still water standardization of pitch, heave, and thrust has practically eliminated relationships involving $V_m$. The high variance in $TH_d$ measurements confirms the high experimental error and suggests that dependence of TH on $V_m$ is the only major relation involving thrust in the series of 17 variables used to describe the experiments (the relationship of Result (c) is relatively minor, and accounts for nearly all of the thrust dependence of $TH_d$ found in this analysis).

(D) *Completion and Extension of the Results:*

If it is desired to carry this particular use of the factorial procedure to completion, the following are recommended, based on these preliminary results:

(1) The data used for the analysis should be expanded to include those of model TMB 4030. This model was also carried through the test procedure utilized for obtaining the model TMB 4057 data. The addition of another model's data would allow a partial breakdown of the factors that involve model description, as well as those that describe model motion.

(2) The assignment of positive and negative signs, in accordance with the list of definitions on page 810 was found to have been somewhat ambiguous. It was not realized that the assignment of signs to wave and encounter velocities implied the corresponding signs on wave length and period of encounter. The result was that the geometric structure involving the vectors representing wave length, wave height, and the $H_w/\lambda_w$ ratio was decreased in dimensionality from two to one.[7] The three points representing these variables were practically colinear, rather than coplanar, with the origin. In essence, the sign ambiguity reduced the independent number of variables from 11 to 10. The five-factor structure [8] is valid, for the sign conventions listed on page 810, but is it probable that a six-factor structure would become apparent on repetition of the analysis with a consistent notational system.

(3) In order to disclose as much information as possible about an experimental system, it is advisable to remove known relationships from the data to as great an extent as possible. Use of the standardizing model runs has accomplished this end with respect to model velocity and thrust. If we perform the same type of "standardization" by using average pitch values, for example, that have been corrected for the velocity of encounter, secondary variation in average pitch should be readily apparent as should variations involving the velocity of encounter. This would be an appreciable assistance in the event that model TMB 3030's data were used, because such action would decrease the dimensionality of the experimental variations, and render the final analysis a little surer.

(4) A preliminary attack on the description of waves reflected from the tank walls has been made. Inclusion of such data could clarify the test results by enlarging the scope of the basic data and hence providing more surety in the factorial results.

(5) Thurstone analyzes the "structure" of the variable representing vectors in their f-dimensional common factor space [9] through the determination of planes defined by several vectors. The intersection of such planes is an indication of a basic factor that is involved in two or more general ways. Also, such an interaction is independent of the arbitrary common factors used to define the spatial location of the variables. Such a factor is an invariant of the structure itself and hence is suitable for meaningful description of the structure. It is probable that energy and momentum functions will be disclosed in this manner. If such is the case, on complete examination, appropriate functions may be calculated from the original data and tried for pertinence in description of the experimental results.

## OPERATIONAL PROCEDURES USED IN THIS PROBLEM

(A) *Summary.*

The operational procedures in this use of the multiple factor method may be summarized as follows:

(1) Selection of variables for use;

(2) Preparation of a table of numerical values for each selected variable representative of each model run;

(3) Factor Analysis;

(4) Examination of a few aspects of the factorial results;

(5) Use of the factorial results for guidance in return to the original tabulation of data for graphical interpretation.

(B) *Selection of variables for use:*

(1) *Available Data:*

The direct data available from the model run test descriptions and the observation films are the following:

(a) Wave Description:
(i) RPM and eccentricity of the wave maker;
(ii) Wave height (double amplitude), velocity, length and period from (a)(i) and standardizing operations.

(b) Model Motion:
(i) Model velocity, and calculated velocity and period of wave encounter:
(ii) Period and phase angle of pitch (relative to wave form) and two measures of pitch description, either plus and minus amplitude or mean angle [10] and total amplitude of motion. The pitch amplitudes are calculated by differences from still water standardizing runs.
(iii) Corresponding period and phase angle of heave, plus two measures of heave description, either plus and minus or mean and total heave distance. Heave distances are calculated from still water standardizing runs.

(c) Powering Data:
(i) Torque, thrust and propeller RPM.

(d) Miscellaneous:
(i) Displacement.
(ii) Physical description of model (dimensions, form factors, etc.).

(2) *Probable Pertinent Parameters:*

(a) Omissions.

Since Thurstone's method will isolate common factors [11] from an experimental complex, all information that is already known to be common to the whole mass of test data becomes irrelevant unless it is desired to confirm the relationship. Unless two or more models' behavior are to be compared, then B(1)(d)(ii), above, should be omitted from examination for this reason. Also, known relationships should not be inserted into the system for examination unless there is a high probability that they can assist in providing an explanation for the experimental behavior of the model. The three apparent variables of item B(1)(c)(i) are readily interlinked to represent only one variable, the force required to move the model under a specific set of test criteria. The thrust is a direct measure of this force and the torque and propeller RPM may be omitted from this consideration of overall model behavior.

The phase angles of items B(1)(b)-(ii), and (iii), depend on some arbitrary datum time or position, chosen for the particular purposes of the analysis. In view of the exploratory nature of this use of the factorial procedure, the particular purpose would be unknown until after the examination. Therefore, the phase angle data is omitted.

Only two parameters are present in the wave descriptions themselves [12] with one additional parameter added by the experimental structure and the assignment of signs based upon the direction of model motion. The influence of the waves on the model will be through the waves themselves, and not through the wave maker, except in a secondary manner. For this reason, items B(1)(a)(i) are omitted from consideration in favor of items B(1)(a)(ii). By the same reasoning, plus and minus pitch and heave values are eliminated in favor of the mean and double amplitudes, in the expectation that the latter would be of more direct physical significance.

(b) Insertions.

The omissions, above, in the original list of experimental variables, leave us 15 variables that represent 11 relatively independent measurements. Three of these "non-independent" variables involve the Doppler effect and its implications when wave and model velocities are affixed with appropriate signs to indicate the experimental reference direction. The fourth "non-independent" variable expresses the redundance of simultaneous use of wave length, wave velocity, and period of wave oscillation.

A maximum of 6 independent factors may be accurately extracted from an 11 x 11 correlation table. An expansion of the list of variables to a larger number does not change the number of extractable factors if these added variables are combinations of those already listed, and if the combinations themselves are also included in the basic structure of the experimental system. However, such an expansion, where the mode of combination of variables is not reflected in the experimental system, will insert an added common factor that does not aid in elucidation of the experimental data. If the total number of common factors now exceeds 6, the maximum number for the basic data, the factoring method no longer supplies a unique configuration for examination.

For this reason, known relationships should be removed from the data to as great an extent as possible, and new combinations of variables should not be added except as they promise to be useful.

With respect to the wave descriptions, it is a matter of question as to which of the following are most likely to be of importance as causative agents for pitch and heave behavior, wave height, wave length, maximum wave slope, or wave frequency (or period). In view of the probability that wave slope can be involved, the ratio $H_w/\lambda_w$ was added as a linear function of maximum wave slope.

Resonant behavior is expected in pitch. A ratio of pitch response to wave excitation would be an indication of this. One of its measures would be Rg Sin $\psi_T/H_w$, where Rg is the radius of gyration of the model about a horizontal axis normal to its path and through the center of gyration. Since the numerical value of a correlation coefficient is not changed by the multiplication of one of the two variables by a constant, Rg was omitted, and the new variable, Sin $\psi_T/H_w$, was added to indicate pitch resonance.

The corresponding insertion of $Z_T/H_w$ as a measure of resonance in heave was not made. If sin $\psi_T/H_w$ proved fruitful this insertion was to be made as a part of a more complete analysis.

The thrust required for still water propulsion of the model is known from the standardizing runs. A new variable $TH_d$ (the thrust difference) was defined by substracting the corresponding still water thrust value from that experimentally determined. It was hoped that any energy or force relation involved in pitching and heaving would become apparent by the use of this new variable and omission of the crude experimental value.

(c) Resulting Parameters.

Revision of the list of parameters, as outlined above, gives us 17 variables for which values are available for each model run. The experimentally known relationships involving the model velocity have been eliminated (possible removal of three common factors—model velocity with pitch, with heave, and with thrust), and two combinations have been added in the expectation that they are already involved in the experimental structure.

The model test run records were then inspected and representative values for each of these parameters were assigned for each model run. There were 114 runs for which values of each of these 17 variables were known.

(C) *Factor Analysis.*

The factor analysis was carried out as indicated in the next Section. Time limitations prevented exhaustive examination of the data, so only a few relations were picked out to demonstrate the scope of the method.

## MATHEMATICAL BACKGROUND

(A) *Introduction.*

A correlation coefficient is a numerical index that provides a means of rating the "relatedness" of two variables. The basis of Thurstone's method of multiple factor analysis is geometric interpretation of correlation coefficients, and subsequent extension of the geometric interpretation of relatedness to include more than two variables.

(B) *Correlation Coefficients.*

Let $x_1, y_1; x_2, y_2; x_3, y_3; \ldots; x_N, y_N$ be a series of N pairs of numbers for which we wish to calculate the correlation coefficient, "$r_{xy}$." We first standardize the unit systems for the numbers x and y.

$$\text{Let } \bar{x} = \frac{1}{N}(x_1 + x_2 + x_3 + \ldots + x_N) \qquad \text{(average x)}$$

$$\bar{y} = \frac{1}{N}(y_1 + y_2 + y_3 + \ldots + y_N) \qquad \text{(average y)}$$

$$\sigma_x = \sqrt{\frac{1}{N}\left[(x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + \ldots + (x_N - \bar{x})^2\right]}$$

(root mean sq. x)

$$\sigma_y = \sqrt{\frac{1}{N}\left[(y_1 - \bar{y})^2 + (y_2 - \bar{y})^2 + \ldots + (y_N - \bar{y})^2\right]}$$

(root mean sq. y)

We may now express the x's and y's in the same number scale, with zero at the average x and y values, by "standard scores" defined by:

$$S_{x1} = \frac{x_1 - \bar{x}}{\sigma_x}, \; S_{x2} = \frac{x_2 - \bar{x}}{\sigma_x}, \ldots, S_{xn} = \frac{x_n - \bar{x}}{\sigma_x}$$

$$S_{y1} = \frac{y_1 - \bar{y}}{\sigma_y}, \; S_{y2} = \frac{y_2 - \bar{y}}{\sigma_y}, \ldots, S_{yn} = \frac{y_n - \bar{y}}{\sigma_y}$$

Using these standard scores, we then define the correlation coefficient, $r_{xy}$, as follows:

$$(1) \quad r_{xy} = \frac{1}{N}(S_{x1} S_{y1} + S_{x2} S_{y2} + \ldots + S_{xN} S_{yN}).$$

It may be shown that $r_{xy}$ must be a number between +1 and —1. The use of $r_{xy}$ as a measure of relatedness may be visualized by a plot of the $S_x$ and $S_y$ values for each of the N data points. If high $S_x$ values are usually associated with high $S_y$ values and low $S_x$ values with low $S_y$ values, the plot will show a roughly elliptical distribution of the N data points, with the major axis along the ++, —— diagonal of the plot. The $r_{xy}$ value will be positive and will approach +1 as the distribution of the N points approaches a straight diagonal line. If high $S_x$ values are usually associated with low $S_y$ values and vice versa, the distribution will again be roughly elliptical, but with the major axis along the +—, —+ diagonal of the plot, the $r_{xy}$ value will be negative, and will approach —1 as the distribution approaches a straight diagonal line. If the N data points approach a random distribution $r_{xy}$ approaches zero.

(C) *Correlations Between Many Variables.*

Using the procedure suggested above, let there be N groups of numbers, with n numbers in each group. We can visualize each group of numbers as the numerical results of measurement of n variables for one experiment, in a set of N similarly measured experiments. We first convert each numerical value to a standard score, as before, to obtain Table A:

TABLE A

Experimental Results for N Experiments, with "n" Variables Measured per Experiment.*

| | | Variable No. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | — | — | i | — | — | j | — | — | n |
| | 1 | $S_{11}$ | $S_{21}$ | $S_{31}$ | — | — | $S_{i1}$ | — | — | $S_{j1}$ | — | — | $S_{n1}$ |
| | 2 | $S_{12}$ | $S_{22}$ | $S_{32}$ | — | — | $S_{i2}$ | — | — | $S_{j2}$ | — | — | $S_{n2}$ |
| Experiment | 3 | $S_{13}$ | $S_{23}$ | $S_{33}$ | — | — | $S_{i3}$ | — | — | $S_{j3}$ | — | — | $S_{n3}$ |
| No. | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | — | — | — | — | — | — | — | — | — | — | — | — | — |
| | N | $S_{1N}$ | $S_{2N}$ | $S_{3N}$ | | | $S_{iN}$ | | | $S_{jN}$ | | | $S_{nM}$ |

* The same set of variables are measured in each experiment.

We then use the data of Table A to calculate the correlation coefficients for each pair of columns by:

$$(2)\quad r_{ij} = \frac{1}{N}\ (S_{i1}\,S_{j1} + S_{i2}\,S_{j2} + \ldots + S_{iN}\,S_{jN}),$$

and obtain Table B.

TABLE B

Correlation Coefficients Between Each Pair of Variables in Table A.

| Variable No. | 1 | 2 | 3 | — | — | i | — | — | j | — | — | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $r_{11}$ | $r_{21}$ | $r_{31}$ | — | — | $r_{i1}$ | — | — | $r_{j1}$ | — | — | $r_{n1}$ |
| 2 | $r_{12}$ | $r_{22}$ | $r_{32}$ | — | — | $r_{i2}$ | — | — | $r_{j2}$ | — | — | $r_{n2}$ |
| 3 | $r_{13}$ | $r_{23}$ | $r_{33}$ | — | — | $r_{i3}$ | — | — | $r_{j3}$ | — | — | $r_{n3}$ |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| i | $r_{1i}$ | $r_{2i}$ | $r_{3i}$ | — | — | $r_{ii}$ | — | — | $r_{ji}$ | — | — | $r_{ni}$ |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| j | $r_{1j}$ | $r_{2j}$ | $r_{3j}$ | — | — | $r_{ij}$ | — | — | $r_{jj}$ | — | — | $r_{nj}$ |
| — | — | — | — | — | — | — | — | — | — | — | — | — |
| n | $r_{1n}$ | $r_{2n}$ | $r_{3n}$ | — | — | $r_{in}$ | — | — | $r_{jn}$ | — | — | $r_{nn}$ |

From the definitions of $r_{ij}$ and of the standard scores, it may be seen that $r_{ij} = r_{ji}$, and $r_{11} = r_{22} = \ldots = r_{nn} = 1$. Table B may then be rewritten as Table C.

TABLE C

Correlation Coefficients Between Each Pair of Variables in Table A.

| Variable No. | 1 | 2 | — | — | i | — | — | j | — | — | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | $r_{12}$ | — | — | $r_{1i}$ | — | — | $r_{1j}$ | — | — | $r_{1n}$ |
| 2 | $r_{12}$ | 1 | — | — | $r_{2i}$ | — | — | $r_{2j}$ | — | — | $r_{2n}$ |
| — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — |
| i | $r_{1i}$ | $r_{2i}$ | — | — | 1 | — | — | $r_{ij}$ | — | — | $r_{in}$ |
| — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — |
| j | $r_{1j}$ | $r_{2j}$ | — | — | $r_{ij}$ | — | — | 1 | — | — | $r_{jn}$ |
| — | — | — | — | — | — | — | — | — | — | — | — |
| — | — | — | — | — | — | — | — | — | — | — | — |
| n | $r_{1n}$ | $r_{2n}$ | — | — | $r_{in}$ | — | — | $r_{jn}$ | — | — | 1 |

Although each r value in Table C was obtained from the experimental values reported for the N experiments, these r's do not represent relations of the *experiments* with one another, but instead represent relations of the *variables* with one another.

(D) *Use of Table C.*

As noted above, we have, by use of correlation coefficients, converted our original table of experimental data into relations between pairs of variables. Let us assume the series of experiments concerns freely falling objects whose kinetic energies are converted into heat by an appropriate device. The variables descriptive of the objects would include weight, density, initial temperature, etc.; those descriptive of the experimental system would include air pressure and temperature, wind velocity, and distance and velocity of fall; those descriptive of energy conversion would include specific heats, initial and final calorimeter temperatures, etc.

From our experimental data we would expect to derive energy conservation relations, data on acceleration under the influence of gravitational attraction, effects on atmosphere drag of object sizes and shapes, etc.

Table C constructed from these data would show high correlation between final object velocity and distance of fall, between object mass and heat produced, between object final velocity and heat produced, etc. If the ranges of object density and shape were wide enough, these variables would also show appreciable correlation with final velocity. In other words, each correlation coefficient would contain the effects of all of the relations involving the two experimental variables concerned, within the limits of the mass of data describing the series of experiments.

In every experimental system there are a finite number of measurable relations between variables. In the example above, we have suggested three as samples (energy conservation, gravitational acceleration, atmospheric drag). Some of these relations may have a close connection with one another. In our example, the object temperature would approach atmospheric temperature as the time of fall increased, or in turn, the atmospheric drag relations would be highly correlated with object-atmosphere thermal equilibrium. Such multiple correlation would reduce the total number of truly independent relationships involved in the set of N experiments. This reduction is the same as that discussed in a different context earlier.

Thurstone has made an assumption of "linear factor loading" [13] that will allow analysis of Table C to separate the several components of each correlation coefficient. He shows that a table of "reference factor loadings" may be constructed as indicated in Table D, below, that will duplicate all but the diagonal entries (unit entries) of Table C, by equation (3).

TABLE D

Table of Reference Factor Loadings

| | | Reference Factor No. | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | — | — | f |
| | 1 | $C_{11}$ | $C_{12}$ | $C_{13}$ | — | — | $C_{1f}$ |
| | 2 | $C_{21}$ | $C_{22}$ | $C_{23}$ | — | — | $C_{2f}$ |
| — | | — | — | — | — | — | — |
| — | | — | — | — | — | — | — |
| Variable | i | $C_{i1}$ | $C_{i2}$ | $C_{i3}$ | | | $C_{if}$ |
| No. | — | — | — | — | — | — | — |
| — | | — | — | — | — | — | — |
| | j | $C_{j1}$ | $C_{j2}$ | $C_{j3}$ | — | — | $C_{jf}$ |
| — | | — | — | — | — | — | — |
| | n | $C_{n1}$ | $C_{n2}$ | $C_{n3}$ | | | $C_{nf}$ |

$$(3) \quad r_{ij} = C_{i1} C_{j1} + C_{i2} C_{j2} + \ldots + C_{if} C_{jf}, \; i \neq j.$$

In Table D, "f" is the number of completely independent relationships between variables in a given set of experiments. The "C's" are interpreted as the projections on a set of "f" Cartesian axes of vectors representing the several variables, (i.e., $C_{i3}$ is the projection of the vector representing variable i on the 3rd of a set of f axes). Equation (3) may be restated as:

$$(4) \quad r_{ij} = h_k h_j \cos \phi_{ij}, \; i \neq j,$$

where $h_i$[14] and $h_j$ are the lengths of the "i" and "j" vectors, and $\phi_{ij}$ is the angle between them.

It may be shown than an infinite number of tables similar to Table D may be constructed that will satisfy equation (3) in the duplication of Table C. The sole requirement is the orthagonality of any one set of axes. These alternate "Table D" correspond to rotations of the reference factor axes, and duplication of Table C corresponds to invariance of the relative location of the n vectors in their f dimensional space as these axes are rotated.

Thurstone also shows that the coefficient "$u_j$" may be introduced to account for the diagonal entries in Table C, by the equation:

$$(5) \quad r_{jj} = 1 = h^2_j + u^2_j = C^2_{j1} + C^2_{j2} + C^2_{j3} + \ldots + C^2_{jf} + u^2_j.$$

The coefficient $u_j$ corresponds to a factor loading, similar to the C's, for all the "uniqueness" in the measurement of variable j. This uniqueness includes errors in experimental measurement and all other experimental variance not shared with one or more of the rest of the n variables taken to describe the N experiments. He describes methods for approximating the h's and for constructing tables of factor loadings, that, by equations (3) and (5), may be used to reconstruct Table C. As implied by comparison of equations (3) and (5), the "uniqueness" is only involved in the diagonal entries of Table C.

(E) *Use of Table D.*

Let us consider two vectors, i and j, defined by Table D. Let us assume that $h_i$ and $h_j$ are both appreciable, close to unity, and that $r_{ij}$ approaches zero (i.e., almost random distribution of the $S_i$ $S_j$ data points). By equation (4), angle $\phi_{ij}$ approaches 90 degrees. Let us draw a new vector, k, normal to vector j and in the i, j plane. If $h_k$ is unity, $r_{ik}$ approaches unity, and since $\phi_{jk} = 90$ degrees, $r_{jk} = 0$. In other words, low correlation between two variables suggests high correlation between one of the two and a new "variable" created by an operation similar to drawing a vector normal to the vector representing the second of the two original variables.

In extension of this idea to an n-variable system, let us return to our fictitious falling body experiments. The energy conservation relation will produce high correlations between object mass, object terminal velocity, distance of fall, and heat produced in the energy conversion device. Some of the remaining variables may be appreciably correlated with one or more of these variables, but not with the group as a whole. This suggests the construction of a new variable, represented by a vector "C," drawn normal to the vectors representing the variables not involved in the energy conservation relation. The r values for the correlations between the new variable and the energy conservation variables would be appreciable. In other words, vector C would represent a generalized energy conservation variable, independent of the remainder of the relationships involved in the series of experiments.

If we were to rotate our f arbitrary reference factor axes so one of them

coincided with C, we could interpret an appreciable projection on this axis as an indication of involvement in an energy conservation relationship. Another way of statement is to say that vector C defines a "hyperplane" [15] through the origin in the f-dimensional space, independent of energy conservation relations. Conversely, if a hyperplane is found in examination of the f-dimensional structure of the n variables, we can say that this hyperplane defines a direction for a vector (or an axis) that is independent of the hyperplane-forming variables' vectors. The nature of this independent vector will be implied in the nature of the vectors with appreciable projections on it.

Continuing this line of reasoning, a two-dimensional plane in the f-dimensional space is determined by two such hyperplane defined vectors, a three dimensional region, by three such vectors, etc. Thus the f axes themselves, after appropriate rotation to positions dictated by the vectors' locations in the f dimensional space, correspond to f separate and independent basic relations involved in the series of experiments.

It is the purpose of this form of factor analysis to find these unique axis locations and to interpret the probable nature of the relations involved. Thurstone describes several graphical methods of analysis of Table D data to accomplish the first of these two purposes. He also provides a considerable discussion of the relative positions of the n vectors relative to these axes as a means of interpreting the relationships. In the case of experimental data drawn from as well known a field as that of Naval Architecture, immediate return to the experimental results should provide considerable assistance in this interpretation.

(F) *Factorial Procedure for the Model Study Data.*

The preceding Section described the variables chosen as representative of the 114 model runs used for illustration of multiple factor analysis. A correlation coefficient table (Table I) was prepared from these experimental results. For convenience, the $r_{xy}$ values were not calculated from the $S_x$ and $S_y$ values, but instead were calculated directly from the experimental data by the equivalent equation:

$$(6)\quad r_{xy} = \frac{\frac{1}{N}\,(x_1y_1 + x_2y_2 + \ldots + x_ny_n) - \overline{xy}}{\sigma_x\,\sigma_y} \qquad [16]$$

Thurstone's group centroid method [17] was used to obtain Table II, the reference factor loading (C's) from Table I. Time was not available to refine the h approximations, so Table II reports only the first approximation to the factor loadings equivalent to Table I. The three relations used as examples of the multiple factor method were found by a preliminary graphical examination of the Table II data.[18] No attempt was made to complete an exhaustive attack on the vector configuration.

(G) *Miscellaneous.*

(1) *Linear Factor Loading*—Subparagraph (D), page 821 notes that Thurstone has proposed a linear factor loading relation which permits Table D to be constructed in accordance with equations (3) and (5). This relation may be expressed as:

$$(7)\quad S_{jk} = C_{k1}\,X_{1j} + C_{k2}\,X_{2j} + \ldots + C_{kq}\,X_{qj}$$

| Variable | Code | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hw | A | | −.88 | +.97 | −.16 | −.47 | −.16 | −.19 | +.12 | −.26 | −.09 | −.35 | −.05 | −.09 | −.45 | −.45 | +.22 | −.06 |
| λw | B | −.88 | | −.94 | .00 | +.51 | +.10 | +.02 | +.06 | +.46 | −.07 | +.45 | +.18 | +.03 | +.40 | +.29 | −.32 | +.06 |
| Hw/λw | C | +.97 | −.94 | | −.10 | −.63 | −.14 | −.13 | +.02 | −.33 | −.03 | −.38 | −.22 | −.05 | −.36 | −.56 | +.25 | −.06 |
| Vw | D | −.16 | .00 | −.10 | | +.12 | −.01 | +.94 | −.58 | +.72 | +.77 | −.02 | +.31 | +.04 | −.32 | +.46 | +.27 | +.05 |
| Tw | E | −.47 | +.51 | −.63 | +.12 | | +.04 | +.13 | +.07 | +.42 | +.09 | +.14 | +.69 | +.01 | +.29 | +.74 | −.08 | +.08 |
| Vm | F | −.16 | +.10 | −.14 | −.01 | +.04 | | +.16 | +.21 | +.08 | +.06 | +.07 | −.15 | +.19 | +.02 | −.04 | −.17 | −.05 |
| Ve | G | −.19 | +.02 | −.13 | +.94 | +.13 | +.16 | | −.56 | +.63 | +.80 | −.01 | +.29 | +.50 | −.32 | +.48 | +.24 | +.04 |
| Te | H | +.12 | +.06 | +.02 | −.58 | +.07 | +.21 | −.56 | | −.35 | −.53 | +.36 | −.12 | −.25 | +.50 | −.22 | −.27 | −.11 |
| $Z_T$ | I | −.26 | +.46 | −.33 | +.72 | +.42 | +.08 | +.63 | −.35 | | +.53 | +.27 | +.48 | +.20 | +.01 | +.62 | +.10 | +.17 |
| Zav | J | −.09 | −.07 | −.03 | +.77 | +.09 | +.06 | +.80 | −.53 | +.53 | | −.15 | +.28 | +.23 | −.34 | +.34 | +.30 | +.31 |
| $T_z$ | K | −.35 | +.45 | −.38 | −.02 | +.14 | +.07 | −.01 | +.36 | +.27 | −.15 | | −.10 | −.08 | +.57 | +.13 | −.31 | −.02 |
| $\psi_T$ | L | −.05 | +.18 | −.22 | +.31 | +.69 | −.15 | +.29 | −.12 | +.48 | +.28 | −.10 | | .00 | +.36 | +.89 | +.15 | −.01 |
| $\psi_{av}$ | M | −.09 | +.03 | −.05 | +.04 | +.01 | +.19 | +.50 | −.25 | +.20 | +.23 | −.08 | .00 | | −.37 | +.25 | +.15 | −.76 |
| Tψ | N | −.45 | +.40 | −.36 | −.32 | +.29 | +.02 | −.32 | +.50 | +.01 | −.34 | +.57 | +.36 | −.37 | | +.07 | −.26 | +.16 |
| $SIN\psi_T/Hw$ | O | −.45 | +.29 | −.56 | +.46 | +.74 | −.04 | +.48 | −.22 | +.62 | +.34 | +.13 | +.89 | +.25 | +.07 | | +.04 | −.14 |
| $TH_D$ | P | +.22 | −.32 | +.25 | +.27 | −.08 | −.17 | +.24 | −.27 | +.10 | +.30 | −.31 | +.15 | +.15 | −.26 | +.04 | | −.01 |
| Δ | Q | −.06 | +.06 | −.06 | +.05 | +.08 | −.05 | +.04 | −.11 | +.17 | +.31 | −.02 | −.01 | −.76 | +.16 | −.14 | −.01 | |

TABLE I

Correlation Coefficients.

(Data: 114 Test Runs of Model No. 4057.)

TABLE II

Factor Loadings Obtained from Correlation Coefficients.

(First Approximation—Group Centroid Method.)

| Code | Variable Symbol | $C_{ij}$ Values (Reference Factor Loadings)* I | II | III | IV | V | $h_i$ Values (Vector Length**) |
|---|---|---|---|---|---|---|---|
| A | Hw | −.66 | −.52 | .45 | −.09 | .00 | .96 |
| B | λw | .61 | .65 | −.37 | .11 | −.04 | .98 |
| C | Hw/λw | −.72 | −.59 | .32 | −.11 | .16 | 1.00 |
| D | Vw | .67 | −.57 | −.11 | −.34 | .35 | 1.01 |
| E | Tw | .67 | .31 | .35 | .08 | −.33 | .89 |
| F | Vm | .08 | .08 | −.09 | .14 | .14 | .25 |
| G | Ve | .67 | −.63 | −.13 | −.02 | .30 | .97 |
| H | Te | −.35 | .58 | .34 | .09 | .18 | .78 |
| I | $Z_T$ | .76 | −.18 | .04 | −.12 | .23 | .83 |
| J | Zav | .54 | −.60 | −.10 | −.24 | .01 | .85 |
| K | Tz | .21 | .53 | .02 | .01 | .57 | .81 |
| L | $\psi_T$ | .63 | −.06 | .66 | .04 | −.23 | .95 |
| M | ψav | .21 | −.36 | −.19 | .91 | .17 | 1.04 |
| N | Tψ | .14 | .72 | .32 | −.10 | .17 | .83 |
| O | $\text{SIN}\psi_T$/Hw | .84 | −.03 | .40 | .21 | −.13 | .96 |
| P | $\text{TH}_D$ | .03 | −.47 | .08 | −.02 | −.09 | .49 |
| Q | Δ | .10 | .10 | −.06 | −.77 | −.23 | .82 |

* The "i" subscript refers to the variable, the "j" to the reference factor or axis.

**Please see page 818 for an interpretation of a "vector length" as applied to a table of reference factor loadings.

For example, the vector representing variable $V_e$ may be represented with projections on the five reference factor axes of: $C_{e1} = .67$, $C_{e2} = -.63$, $C_{e3} = -.13$, $C_{e4} = -.02$, $C_{e5} = .30$, and by equation (5), $h^2_e = .97^2 = .67^2 + .63^2 + .13^2 + .02^2 + .30^2$.

where $S_{jk}$ is the standard score for experiment j in variable k. There are q "X's" where, as indicated by the second subscript, each is referred to experiment j. These are understood to be a series of standard scores for experiment j that describe the composition of this experiment with respect to q independent "factors." Each X is accompanied by a C value. These C's as indicated by the subscripts, weight the respective X values to obtain the experimental value of $S_{jk}$. The qualitative interpretation of equation (7) is that each experimental S value is a linear sum of quantities dependent on the detailed structure of the particular experiment in the group of N experiments and on the relation of the variable concerned to the geometric axes implied by the comparison of the experiment with the body of the experiments. The number "q" is n + f, where f independent axes are sufficient to describe the vectors determined by the $r_{ij}$ values of Table C where $i \neq j$. Each $C_{kq}$ value where $q > f$ is zero, except for $C_k$ (f + j), which is the same as $U_j$. These zero entries correspond to the "unique" nature of $U_j$.

(2) *Maximum Value of "f" for a given "n."*—It may be shown that the configuration of vectors described by Table D is invariant only when f does

not exceed a maximum value dependent on n. Below is a table of maximum f values as a function of n.

| Maximum Value of "f" | No. of Independent Variables "n" |
|---|---|
| 1 | 3 |
| 2 | 5 |
| 3 | 6 |
| 4 | 8 |
| 5 | 9 |
| 6 | 10 |
| 7 | 12 |

(3) *Use of Raw Data to Establish Table I.*—The use of a correlation coefficient to describe relatedness implies that this relatedness is superimposed on a purely random fluctuation of the values of the variables. In view of the fact that some of the experimental variables were imposed in a systematic manner to establish the N experiments, and in view of the non-linear nature of some of the measurements (Sin $\psi_i/H_w$ for example), it is obvious that statistical randomness is not represented in the data. It is possible to use re-scaling procedures that will distort the raw numerical values to a closer approximation to randomness. However, Thurstone reports that the results of factor analysis on raw and rescaled data are almost identical, so refinement by re-scaling was not carried out in this example.

(4) *Nature of the Coordinate Axes.*—In our discussion of the broad features of the f-dimensional space that may be used to describe the experimental results, we did not identify the coordinates themselves, except to state that they were orthagonal. Also, we noted that any one set of f orthagonal axes in the space containing the N points was equivalent to any other set of axes spanning the same space. One specific orientation of axes was qualitatively discovered as defined by the n variables' vectors and as representation of f basic relations in the experimental data.

The identification of the scalar production of two variables' vectors with their correlation coefficient (equation (4)) allows us to say an orthagonal arrangement of the axes corresponds to mutual independence of whatever is indicated by these axes, within the limits of the experimental data. Thurstone has chosen to call a set of these axes equivalent to a set of independent "common reference factors." He terms the f-dimensional region the "common factor space." A "common factor" is therefore a relationship common to a mass of experimental data that may involve two or more of the variables measured in the series of experiments.

(5) *Colinearity of Vectors Representing* $H_w$, $\lambda_w$, $H_w/\lambda_w$.—Combination of equations (3) and (4) gives us:

$$(8)\quad \text{Cos } \phi_{ij} = \frac{C_{i_2} C_{j_1} + C_{i_2} C_{j_2} + \ldots + C_{if} C_{jf}}{h_i h_j}$$

Substitution of the C and h values from Table II for the vectors representing $H_w$, $\lambda_w$ and $H_w/\lambda_w$ gives us:

$$\text{Cos } \phi_{ij} = -0.99 \quad (i = H_w,\ j = \lambda_w)$$

$$= +0.98 \quad (i = H_w,\ j = H_w/\lambda_w)$$

$$= -0.99 \quad (i = \lambda_w,\ j = H_w/\lambda_w)$$

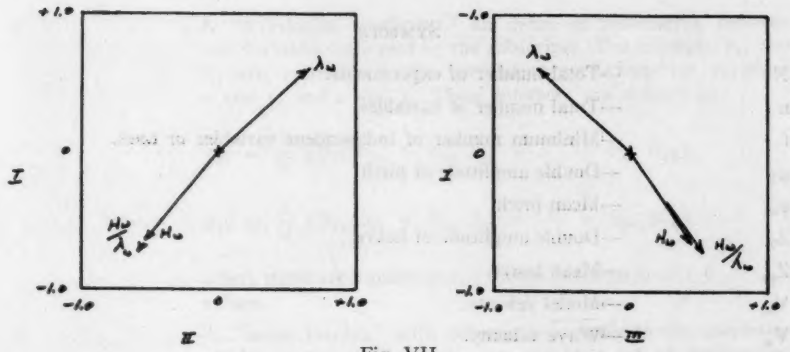


Fig. VII.

Plot of the vectors representing $H_w$, $\lambda_w$ and $H_w/\lambda_w$ in the I-II and I-III planes, using the data of Table II:

| | $C_{ij}$ Values* | | |
|---|---|---|---|
| Variable | $C_{i1}$ | $C_{i2}$ | $C_{i3}$ |
| $H_w$ | —.66 | —.52 | .45 |
| $\lambda_w$ | .61 | .65 | —.37 |
| $H_w/\lambda_m$ | —.72 | —.59 | .32 |

* i.e., the terminal point for the vector representing $H_w$ is plotted at I = —.66, II = —.52, III = .45.

These three cosine values are practically unity indicating colinearity of the three vectors. An illustration of the graphical interpretation of the factor loadings is provided by Figure VII, where the C's for these three vectors (Table II data) are plotted for the I-II and I-III planes.

(6) *Independence of Variables.*— There is a statistical index, the "coefficient of alienation" which is defined as the fraction of the variation of a dependent variable that is alienated from or independent of an associated variable.[19] This number, "$(C.A.)_{xy}$" is related to a correlation coefficient by

(9) $(C.A.)_{xy} = \sqrt{1 - r^2_{xy}}$, where x and y are the two variables.

If we restate equation (5) as:

(10) $u_j = \sqrt{1 - h^2_j}$,

and refer to equation (4), $r_{ij} = h_i\, h_j \,\text{Cos}\, \phi_{ij}$, the equivalence of $u_j$ and $(CA)_{jj}$ is suggested. The difference between the use of $H^2_j$ and $r_{jj}$ as a measure of the "self-correlation" of the set of values recorded for variable j in the series of N experiments is the exclusion of the unique component in $h_j$. In other words, we can say that $u_j$ may be regarded as "that fraction of the variation of variable j that is unique, or undefined by the other variables used to describe the series of N experiments."

## Symbols

$N$ —Total number of experiments.

$n$ —Total number of variables.

$f$ —Minimum number of independent variables or axes.

$\psi_T$ —Double amplitude of pitch.

$\psi_{av}$ —Mean pitch.

$Z_T$ —Double amplitude of heave.

$Z_{av}$ —Mean heave.

$V_m$ —Model velocity.

$V_w$ —Wave velocity.

$V_e$ —Velocity of wave encounter.

$\lambda$ —Wavelength.

$H$ —Wave height.

$T_w$ —Period of waves.

$T_e$ —Period of wave encounter.

$T_\psi$ —Period of pitching.

$T_z$ —Period of heaving.

$\Delta$ —Displacement.

$TH$ —Thrust.

$TH_d$ —Thrust difference.

$R_g$ —Radius of gyration in pitch.

$\bar{x}$ and $\bar{y}$ —The average values of the x and y series of numbers, respectively.

$\sigma_x$ and $\sigma_y$ —The root mean square deviations of the x and y numbers, respectively, from their mean values, also known as the "standard deviations" of x and y values, respectively.

$x_1, y_1;$
$x_2, y_2; \ldots;$
$x_n, y_n;$ —A series of n pairs of numbers.

$S$ —A "standard score" for a numerical value. For example, $S_{x_1}$, $S_{y_3}$, $S_{i_2}$, $S_{j_n}$ are, respectively, the standard scores corresponding to $x_1$, to $y_3$, to $i_2$, and to $j_n$. These numbers are defined by:

$$S_{x_1} = \frac{x_1 - \bar{x}}{\sigma_x}, \quad S_{y_3} = \frac{y_3 - \bar{y}}{\sigma_y}, \quad S_{i_2} = \frac{i_2 - \bar{i}}{\sigma_i}, \quad S_{j_n} = \frac{j_n - \bar{j}}{\sigma_j},$$

where $\bar{i}$, $\bar{j}$, $\sigma_i$ and $\sigma_j$ have definitions similar to $\bar{x}$ and $\sigma_x$; where $i_2$ is the second of a set of numbers $i_1, i_2, \ldots, i_n$; and where $j_n$ is the "nth" of a set of numbers $j_1, j_2, \ldots, j_n$.

r —A "correlation coefficient," an index of relatedness, between two variables indicated by the subscripts. For example, $r_{xy}$ and $r_{ij}$ are, respectively, the correlation coefficients for variables x and y, and i and j. These numbers are defined by:

$$r_{xy} = \frac{1}{N} (S_{x1} S_{y1} + S_{x2} S_{y2} + \ldots + S_{xn} S_{yn}),$$

$$r_{ij} = \frac{1}{N} (S_{i1} S_{j1} + S_{i2} S_{j2} + \ldots + S_{in} S_{jn}),$$

where there are n pairs of x, y values and n pairs of i, j values.

C —A "factor loading" with subscripts, to indicate the projection of the vector of a variable on one of a set of independent (Cartesian) axes. For example, $C_{12}$, $C_{i3}$, $C_{jf}$ are, respectively, the projections of vector "1" on axis "2," of vector "i" on axis 3, and of vector j on axis "f."

h —The length of a vector representing a variable in the common factor space, for example, $h_i$ is the length of the vector representing variable i.

$\phi_{ij}$ —The angle between vectors i and j.

$u_j$ —The factor loading for all unique components in the measurement of variable j in a given set of experimental data. This unique factor loading is defined by:

$$u^2_j = 1 - (C^2_{j1} + C^2_{j2} + \ldots + C^2_{jf}) = 1 - h^2_j$$

## References


1. These data were concurrently analyzed by Reed Research, Inc., for the Taylor Model Basin.
2. The "multiple factor method" presented in this paper is that described by L. L. Thurstone in his book "Multiple Factor Analysis," University of Chicago Press, 1947.
3. It should be noted that this observation is made upon analysis of pitch data subsequently found in error. With respect to these data, the statement is correct and is used as a demonstration of the method. Paragraph (3) on page 813 explains the error and shows the experimental results after its correction.

4. More properly, his procedure provides a means of finding vectors that represent average values of the variables, where the vectors' origins are taken to be at the common zero of the f-dimensional coordinate axes. The word "vector" has its usual mathematical meaning of a definite length associated with a specified direction.

5. If $\psi_{max.}$ and $\psi_{min.}$ represent the highest and lowest pitch angles of a given test run, $\psi_T = \psi_{max.} - \psi_{min.}$ and $\psi_{av} = \frac{1}{2} (\psi_{max.} + \psi_{min.})$. $Z_T$ and $Z_{av}$ are correspondingly defined.

6. "Rg" is the radius of gyration of the model in pitch. Please see page 817 for a more complete description of this composite variable.

   NOTE: For convenience the parentheses around (Sin $\psi_T$) have been omitted in subsequent discussion of this sine function.

7. "Dimensionality" and "colinearity" of these vectors refers to their relative position in the f-dimensional space mentioned previously. This colinearity is illustrated on page 826 ((5).)

8. "Five-factor structure" refers to this particular use of factor analysis, where f was found to be 5.

9. Please see Section "Mathematical Background" for a discussion of the geometric relationships implied in this paragraph. The f-dimensional region that may be used to describe the data has been termed the "common factor space" by Thurstone.

10. "Mean angle" of pitch is understood to be the arithmetic mean of the pitch angles during a full cycle of pitching. It is approximated by the arithmetic mean of the plus and minus extremes.

11. A "common factor" is some underlying relationship between the variables used in the analysis, when the relationship is common to the whole mass of experimental data.

12. This must be so, since only two variables, eccentricity and RPM are available in the wave maker.

13. Please see "Multiple Factor Analysis" for a detailed discussion of the factor loading concept and its consequences.

14. The squares of the h values are called the "communalities" of the variable's vectors.

15. In an f-dimensional space ($f>3$), a hyperplane is described by f—1 dimensions.

16. Treloar, "Elements of Statistical Reasoning," p. 96.

17. "Multiple Factor Analysis," Chapter VIII.

18. This graphical examination included inspection of the projections of the 17 vectors on four independent planes defined by pairs of the Table II arbitrary common factor axes. In addition, a rotational system was used to obtain indications of coplanarity with a given reference vector by check of colinearity of similar projections, using a set of orthagonal coordinates normal to the reference vector.

19. Treloar, "Elements of Statistical Reasoning," p. 126.

# RUSSIA'S SUBMARINE DEVELOPMENT (1850-1918)

LIEUTENANT COMMANDER BERNARD M. KASSELL, USN

THE AUTHOR

Enlisted in 1931. Appointed Electrician in 1940, Ensign 1942, and up to Lieutenant Commander in 1949. Served in *Utah, Idaho, Yorktown, Morris* (DD417), *Canopus, Otus, Snowden* (DE246), *Casa Grande* and is now Repair Officer in *Bryce Canyon* (AD36). Served as material assistant on the staff of Commander Destroyers Atlantic Fleet in 1944 and was Electronics Officer at the Fleet Training Center, Norfolk, prior to spending five semesters at Cornell University, where he majored in Russian, the language, economy, history, etc., and took the peripheral subjects which would tie in to the picture. Became interested in Russian shipbuilding when he found that little or no collected material existed on the subject. Since that time, two years ago, he has found a considerable amount of material available. All that is necessary, evidently, is a lot of digging for sources, one of which leads to another, and plugging to do the translations. At the moment he is trying to find the time to do some translations so as to round out a paper started on the shipbuilding industry during the first five-year plan, and then branch out into the other plans so that the entire picture may clear up a little. Has been awarded the area ribbons, all three, the Pacific with one star for having been in the Philippines when the war started, the Philippine Defense, Occupation and China Service medals, Defense medal with fleet clasp, Word War II Victory medal and the enlisted good conduct with one star. Most of his service has been in engineering or materiel work, although he was executive officer and later commanding officer of the *Casa Grande*.

FOREWORD

Every Great Power has its "silent service," its submarine fleet which functions best when war comes. It is not too difficult for the naval historian to trace the development of these various fleets, for most countries have prided themselves on the accomplishments of their submarines and the men who serve in them. As evidence of the accomplishments of their fleets, the various naval ministries have given their blessings to those writers who desire to publicize the deeds of the underwater arm.

There is, however, one power about whose submarine development little, if anything, has been written. That power is Russia.

The present article has been written so that a gap in the overall picture of submarine development may be filled in.

The author is indebted to Mr. George N. Taube, former Lieutenant Commander in the Russian Imperial Navy, who graciously permitted the author to read several original manuscripts in the old Russian orthography and extended the courtesy of the archives of the Association of Former Russian Naval Officers in America, Inc. Certain of the materials contained herein are used with the permission of the publishers of that organization's periodical, *Morskiye Zapiski* (The Naval Records).

# RUSSIA'S SUBMARINES (1850-1918)

## DEVELOPMENTS PRIOR TO 1900

The present day numerical superiority of Russia's submarine fleet is a well-known fact. What is not so well known is the fact that Russia, under the Czars, took a leading role in the construction and development of submarines. Little original work appears to have been carried on in Russia prior to the middle of the 19th century, despite the fact that prior to 1850 experimental work was carried on in virtually every country but Russia. After that date, however, every important submarine inventor, at one time or another, took his wares to Russia. Here the inventor was assured of a welcome, for the Russians took an interest in submarines which has persisted to this day.

This interest in underseas craft stemmed from the fact that Russia's coast line was singularly vulnerable about its periphery. Accordingly, it was reasoned, a means must be developed to fit the primary strategic concept of the time—defense of the coast. While anchored mines and coastal defense batteries could protect the harbors, it was still necessary to develop some mobile means of defense, a type of defense for which the submarine was peculiarly suited. There is some evidence to indicate that offensive use of the submarine was contemplated by the Russians, but this concept was years in the future, and will be discussed later.

The use of submarines along the coast was not a concept confined strictly to Russia. At the turn of the century the following statement appeared in the Boston *Journal:*

> "The truth seems to be that the submarine boat does not and cannot revolutionize naval warfare. It is an auxiliary at the best—an auxiliary for coast and harbour defense. So imperative are the limitations of their peculiar design that the submarine boats cannot go far to sea, and can *never accompany cruising squadrons.*" [Italics supplied.]

Other nations were even more pessimistic, as witness the statement credited to Germany's Admiral Von Tirpitz at about the same time, 1900:

> "It is true that submarine boats have improved, but they are as useless as ever. Nevertheless, the German Navy is carefully watching the progress, though it has no reason to make experiments itself."

Despite this pessimism, which, from 1850 to 1900, was even deeper, Russia carried on with her submarine program. The German inventor, Wilhelm Bauer, who built his first submarine in Kiel in 1850, turned up in Russia shortly thereafter and was commissioned to build one boat for the Russian Admiralty.[1] This first Russian-built submarine was completed at the Leuchtemberg Works in St. Petersburg, in May, 1855, and was turned over to the Admiralty in November of the same year. The boat was dolphin-shaped, approximately 52 feet in length, with a beam of slightly more than twelve feet, and having a draught of eleven feet. The hull frame was of iron, substantial enough to withstand submersion to 150 feet. One hatch, in the bow, permitted entrance and exit. Propulsion was by means of a stern propeller, driven by four wheels, each seven feet in diameter, operating on the treadmill principle. A Russian lieutenant, Fedorovitch, was assigned to the new vessel. In accordance with what appears to have been accepted Russian practice at the time, his main task was to learn all that he could from Bauer, after which Bauer was to depart the country.

This method of educating Russian shipbuilders extended to all types of shipbuilding. It seems to have started during the time of Peter the Great, who sent representatives to the western European shipyards to learn all they could. Contracts, or orders, placed with European shipbuilding firms, included a stipulation that plans were to be fur-

nished for all vessels. The idea was, that once one ship was built and its plans were available, the representative, who had followed the construction from the laying of the keel to the trials, could then return to Russia, set up shop, and duplicate the procedures.

Bauer, however, seems to have been too crafty for the Russians, who detested him as a tiresome innovator. While the Russians wanted the boat very much, they were not prepared to take its inventor as part of the bargain. In any event, the trials, as arranged by a special commission, ended in near disaster. The submarine's propeller became entangled in a mass of seaweed, and thus ended Bauer's 134th, and last, attempt at submarine navigation in Russia. Although Bauer refloated the boat, after four weeks work, it was later lost at sea off Ochda.

Bauer's efforts stimulated Russian inventors, and a Russian officer named Spirindov drew up plans for a submarine to be used in and around Sevastopol. The boat was to operate on the suction and propulsion of water, similar to the hydrostat developed by Dr. Payerne in 1843. This effort never got beyond the planning stage, however.

In 1868, the Winan, or Vinan, Yard, on the banks of the Neva River, near what was then St. Petersburg, launched a submarine of over 600 tons. It had been planned by Alexandrovski, and little is known of the details. The boat made several trials, but they were not too successful. It is reported that the boat finally submerged to too great a depth and was crushed.

From 1877 on Russian submarine construction revolves around an inventor whose efforts extended well into the 20th century, and who designed and built at least five different classes of submarines. In addition, he developed torpedo tube mounts and accessories for use in submarines.

This Russian engineer, Drzewiecki, or Dzhevetsky,[2] constructed, in 1877, a small submarine which was similar in form to the first Holland boat. It was a tiny craft, thirteen feet in length, and was propelled by a screw worked by foot pedals, much like a bicycle, the power being transmitted by cogs. The hull was steel, with the lower portion forming a ballast tank. A conning tower was placed in the center of the boat, and the lone occupant of the boat could catch glimpses of the horizon from this tower. Two interesting features were incorporated in the design.

One was a small pump, driven from the propulsion gear, the purpose of which was to supply fresh air and expel foul air from the interior of the boat. The other was the use of what amounted to a leather glove on each side of the conning tower for the purpose of fixing explosives to the hulls of ships. The explosives, probably miniature torpedoes, were to be carried outside the boat, within easy reach of the gloves, and were enclosed in boxes strung together and fitted with rubber suction cups to ensure their adherence to the hulls of vessels being attacked.

Dzhevetsky's efforts attracted the attention of the Government, and he was ordered to construct an improved, larger, vessel. This commission was carried out in St. Petersburg in 1879, and was a tremendous step forward.

This second effort was almost twenty feet long, capable of accommodating four men, who sat back to back, two facing forward and two aft. The crew turned the propellers, there were two, one forward and one aft, by means of pedals. Two pumps were installed in this class, one for air, and the other for dumping and filling the ballast tanks. The air pump forced the air over beds of caustic soda to rid it of carbon dioxide. Fresh air was provided by a tank of compressed oxygen. A circular dome, fitted with stout glass, covered the heads of the men, and the forerunner of the periscope, an optical tube, was fitted to the forward end of the

conning tower. This tube contained reflecting prisms and a magnifying glass at the lower extremity of the tube so that the helmsman could see what was going on on the surface when the boat was submerged. Diving was accomplished by flooding the ballast tanks and manipulating the forward propeller, which appears to have been an embryonic bow-plane arrangement. Two torpedoes were fitted to the exterior of the boat in grooves recessed into the hull close to the top of the boat. These missiles could be released from inside the boat and attached to the keel of a ship under attack by means of rubber cushions, or fenders, placed on either side of the torpedo. These cushions were filled with compressed air from inside the boat, and when released were supposed to float up under the keel and remain. Since they were never used in actual wartime attacks, their efficacy is problematical. Nevertheless, the idea, for the time, was a novel one.

Trials of this boat were conducted on Lake Gatchina during the winter of 1879, and appear to have been successful. In any event, the Minister for Coast Defense ordered Dzhevetsky to build fifty similar vessels.

This new class, the third designed by Dzhevetsky, was similar to the second; the length was the same. The chief difference was in the propeller arrangement. The new class had one propeller, located aft, capable of movement in every direction. A new feature was the introduction of traveling weights, which could be moved the length of the boat, to ensure stability and evenness of course. It was thus possible to regulate the center of gravity and to give the proper angle of inclination when diving or surfacing. Other features were identical with those of the second class.

So far as can be determined, fifty of this class were actually built and a school for the study of this type was established. It is reported that these boats maneuvered constantly in Kronstadt Harbor for many years.

Unfortunately, speed was lacking. Seldom did they exceed three knots, even under the most favorable conditions of weather and sea.

The next forward step, an obvious one, was the development of a mechanically-driven submarine. Dzhevetsky, about 1884, replaced the pedals with an electric motor driven by storage batteries placed fore and aft. In order to compensate for the added weight, two men were eliminated from the crew. The remaining two men sat back-to-back; the propeller was fixed; a rudder was fitted. Speed, increased to four knots, was still inadequate, however.

In 1886, the Ministry of Coast Defense passed from the jurisdiction of the Admiralty to that of the War Department. The Minister of War considered these little vessels to be useless and unnecessary, and all experimental work was abandoned.

Writers of the time thought the decision a wise one, for, despite the fact that the boats were ingenious, and fairly successful, their lack of size and speed made them of little value for war purposes. The logic of this reasoning cannot be denied, but one cannot help but wonder what might have happened, particularly during the Russo-Japanese War, had the experiments continued. The limitations of the submarines of the period were recognized, even by the designers, but without the encouragement of backing, financial as well as military, the time lost in bringing later plans to fruition was irretrievable.

Dzhevetsky was not easily discouraged. In 1888 he presented plans for an improved type of submarine, this one to have a displacement of 150 tons. Nothing came of these plans, no doubt because of the antipathy of the War Department.

Twelve years were to elapse before the fertile brain of Russia's foremost inventor produced plans for another

new type of submarine. In 1896 he submitted plans in the competition opened by the French Naval Ministry. This boat was to have a displacement of 190 tons, capable of a speed of 15 knots on the surface, and 12 knots submerged. The increased submerged speed was to result because the designer had come to the conclusion that it was unnecessary to submerge completely in order for the submarine to carry out its mission. Dzhevetsky did not foresee the role submarines were to play in later years. His reasoning stemmed from the submarine tactics of the times, which assigned to the submarines tasks which required them to operate at bare surface levels. More correctly, most work was done in the "awash" position. Thus, the water cushion gave the submarine hull adequate protection from surface fire and a true submarine was not needed. This new design was, in effect, a "submersible" rather than a submarine. Steam was to be the motive power for above water navigation and an electric motor, driven by storage batteries, was to be used only in case of grave danger which would require the boat to actually go below the surface. The capacity of the batteries limited the boat to not more than three hours below the surface at full speed.

Otherwise the boat was to be fitted with routine appliances for maintaining stability, etc. One feature which was new, however, was the arming of the boat with torpedoes which were to be launched from a special launching cradle, the invention of the designer.

The French Ministry awarded Dzhevetsky a prize of 5000 francs for his design and accepted the launching cradle completely. The cradle was adopted by the French Navy for all their vessels of the submersible type. Although the French Ministry gave careful consideration to the submersible design, there is no evidence to indicate that it was accepted for production. The French may well have foreseen the ultimate use to which submarines were to be put in later years.

## THE PRE-WORLD WAR I ERA

Whereas France and Russia were definitely interested in submarine development England and the United States displayed a singular lack of interest in sponsoring such developments. France had undertaken a program which was to yield about forty submarines by 1900 or 1901. We have seen something of Russian interest. At the time when the French program was to be fulfilled, the United States had about eight submarines, England five. The New York *Journal* claimed, at the turn of the century, that three rear-admirals, Chiefs of Bureaus of the Navy Department, appeared before the Naval Committee of the House of Representatives to protest against the construction of any more submarine boats. Lord Goshen, First Lord of the Admiralty, during a debate, about the same time, on the naval budget in the House of Commons, speaking against the construction of submarines, declared that "the submarine is a weapon of the poor and the weak."

Parliament thought otherwise, for five Holland-type submarines of 105/-120 tons displacement were ordered for the English fleet. These were placed in service in 1902.

Russia became concerned at this sudden interest in submarines on the part of the English, and decided to augment her submarine strength as well. A commission, composed of Lieutenant M. N. Beklemishev, a graduate of the Naval Academy in the Ship-Constructor Branch, a mechanical engineer named Goryunov, and a naval engineer named Bubnov, was appointed.

Engineer Bubnov was the designer, and in May, 1901, presented his plans to the Naval Technical Committee. The plans, as drawn, contemplated the construction of a submarine of 113 tons displacement. In July, 1901, the order for its construction was placed with the Baltic Shipbuilding Yard in Petersburg. In the fall of the year, when orders were being placed for the various mechanical components, Goryunov insisted that the propulsion units be Diesel engines. At a time when all other submarines had gasoline propulsion, the proposal appeared to be too radical, and Goryunov was ousted. Lieutenant Beklemishev took over the outfitting of the boat.

The Holland interests, in the meantime, offered to build a boat of this type for the Russian Government, but this offer was declined.

*Delfin,* as this boat was to be called, was launched in June of 1903, at a cost of 388,000 rubles, approximately $300,000. Characteristics of this submarine, the first of its type, were as follows:

| | |
|---|---|
| Displacement | 113/135 tons |
| Length | 63 feet |
| Beam | 12 feet |
| Draught | 11 feet |
| Speed of submersion | 20 minutes |
| Surface speed | 9 knots |
| Submerged speed | 4.5 knots |
| Crew | 2 officers, 18 men |
| Armament | 2 reversible torpedo tubes of the Dzhevetsky type |

Trials, which were completely successful, led Bubnov, in the fall of 1903, to propose the construction of a better boat of 140 tons displacement with a speed of 14 knots. The order for its construction was delayed until just before the outbreak of the Russo-Japanese War.

The outbreak of this conflict, on January 26, 1904, forced the Naval Ministry to take special measures for the rapid strengthening of the Far Eastern Squadron.

These measures included the placing of an order with the Baltic Yard, in February, 1904, for the construction of four submarines of the Bubnov type, to have a displacement of 140 tons; the purchase, in America, of *Protector* (137/174 tons) from Simon Lake, as well as *Fulton* from the Holland interests. In addition, an order was placed with the Nevsky Yard in St. Petersburg for five boats of the Holland type, as well as an order for five boats of the Lake type to be built in America.

The desperate straits in which Russia found herself led the Ministry to undertake the ordering of a wooden submarine which had been designed by a Lieutenant Botkin, as well as the alteration of *Keta,* a Dzhevetsky-type submarine which had been built in 1886.

Germany, at this time, presented to the Russian Government the 16-ton *Forel,* an experimental all-electric submarine. In April, 1904, the Germania-Werft Yard, in Kiel, was given an order for three boats of a similar type. to have a displacement of 210/235 tons. to cost 1,200,000 marks.

Mention is also found of the fact that a Count Sheremetev contributed 400,000 rubles and ordered one additional boat of the Bubnov type from the Baltic Yard, stipulating that it be named *Feldmarshal Graf Sheremetev,* in honor of his ancestor, a collaborator of Peter the Great.

*Delfin* was pressed into service as a training ship for officers and crews

being assigned to the new construction. When *Delfin* sank, the circumstances of which disaster will be detailed later, all training was suspended, for the only other active submarine was the virtually useless *Forel.* It is a sad commentary on the state of this arm of the Navy that, despite all the experiments which had been carried on, and despite all the money which had been spent on the development of submarines prior to the unification of the services, when war did come, no facilities were available for the training of personnel in so specialized a field as submarine warfare.

We are indebted to the *Naval Records,* and to the former Russian Admiral, A. V. Plotto, for the story of the disaster which overtook *Delfin* in July or August, 1904. One date, as given by V. A. Merkushov in his unpublished account, *Brief Outline of the Development of the Russian Submarine Fleet, 1901-1917,* and upon which the author has drawn for details, is July 16, 1904. Plotto is less definite as to the date, but more precise as to what happened. His account, as translated by the author, reveals one of those series of unrelated events, which, when occurring coincidentally, all too frequently lead to disaster:

". . . The accident occurred at 9 o'clock in the morning and I arrived at 10:30. . . . In general the first impression was rather overwhelming. The accident occurred during a practice dive by the school crew. For this training 35-40 ratings were assigned to the boat, along with a few inexperienced officers, and one of the more experienced officers. (NOTE: The normal crew was two officers and eighteen men. Author.) The latter, during the instruction period, took command of the boat. On this particular occasion the boat was in a half-submerged condition. Since it was forbidden to smoke in the boat, Lieutenant Cherkasov, the diving instructor, remained in the conning tower hatch to smoke a cigarette. A passing Kronstadt side-wheel steamship caused a large wave which washed over the boat, which at once went to the bottom. Cherkasov did not lose his wits and began to close the hatch. . . . Had this effort been successful, all would have been saved. The water which had entered the boat could have been quickly pumped out before it could pour over the storage batteries. Unfortunately, one of the apprentices, in a panic, threw himself on the ladder in the hatch and succeeded in forcing himself under the hatch cover, where he became caught. Enough space remained for the water to come through. The boat filled with water, a short circuit occurred, followed by an explosion of the hydrogen gas and gasoline fumes. . . ."

The commanding officer and about twenty-five of the crew were lost. The boat was later raised and given a major overhaul, but training was ended. In fact, the personnel assigned to the new construction had no instruction. Plotto says:

". . . I reproach Bubnov, of course, for the fact that during the entire time of the stay at the Baltic Yard, he did not find time to deliver, to the officers destined to sail on submarines, at least several lectures on the theory of submarine operation and on the theory of thermal engines. . . ."

In July and August, 1904, the Baltic Yard launched six boats of the Bubnov type, *Feldmarshal Graf Sheremetev, Kasatka, Skat, Nalim, Markel* and *Okun,* all 140-ton boats, costing 400,000 rubles each.

Only one of the boats, *Kasatka,* was assembled and tested. The others, in disassembled condition, were shipped by rail to Vladivostok and assembled in that port. This was the beginning of submarine prefabrication in Russia. Although prefabrication was used extensively by the Soviets prior to World

War II, Czarist Russia must be credited with the origination of the idea.

*Kasatka* differed in some respects from *Delfin*—and for the worse, as it developed. Where the latter had gasoline engines capable of driving the boat at 9 knots, the former, as will be seen, did not approach this speed. The most glaring design fault, in the *Kasatka* class, lay in the fact that the conning tower, for some unexplained reason, was placed close to the bow. Trials of the one boat were held in Kronstadt, and were unsuccessful, primarily because *Kasatka* was not ready.

In the first place, the gasoline propulsion engines were never delivered. These engines, ordered from Nuerenberg, Germany, were not ready in time to be installed. As a makeshift arrangement, it was decided to install a small dynamo of the Panier type, to be used for charging the storage batteries. Then it was decided that this dynamo was to be used for electric-drive on the surface—changing over to batteries when submerged. This decision resulted in a reduction in speed to 4½ knots on the surface, even in calm weather. Submerged speed remained at 7 knots, however. One gain was made from this arrangement. Because the fuel tank installation had been designed for gasoline engine drive, the smaller consumption by the dynamo prime mover gave the boats a far greater cruising radius than was anticipated.

In actual operation the boat was a source of continual headaches to the personnel. Submersion was a difficult maneuver, for trimming was virtually impossible. The difficulties were overcome, not by the designers, who, so far as can be determined, never entered any of the boats once they were afloat, but by the operating personnel.

N. A. Smirnov, instructor in physics and mathematics in the Torpedo Officer's School, and later second officer in *Kasatka*, is credited with solving the mystery of failure to trim properly, as well as developing a cure for the ailment.

The transference of the conning tower to a point well forward on the hull resulted in the displacement of the center of buoyancy too far forward, so that constant manipulation of the bow rudders, or planes, which were manually operated, was required. Time was lacking for the accomplishment of the necessary alteration, and Smirnov came forward with a proposal involving the installation of a false conning tower placed well aft. Installation of this tower solved the problem for the *Kasatka*, and the boats shipped to the Far East, reported that now the smallest rudder changes were answered, with very little movement necessary to obtain the results desired.

As usually happens, one thing led to another. Since no provisions had been made for carrying fresh water, Lieutenant Zabotkin, skipper of *Feldmarshal Graf Sheremetev*, suggested carrying fresh water in the false tower. The idea proved to be a good one, eliminating the necessity for installing fresh water tanks in the hull.

There remained one problem, however. The hulls of the boats had been built to withstand a pressure of 300 feet. New conning towers, to be ordered later, if built to this specification, would make the boats top-heavy. As it developed, when the new conning towers were installed, in 1906-1907, they were the weakest part of the boat, with the safe depth being only 120 feet.

Ultimately all these boats arrived in Vladivostok, where they were assembled and altered in accordance with Smirnov's suggestion. Plotto tells us that from January, 1905, until the armistice, fourteen boats arrived in Vladivostok:

| | |
|---|---|
| Bubnov type *(Delfin, Forel)* | 2 |
| Bubnov type (improved) | 5 |
| Holland type | 3 |
| Lake type | 3 |
| Botkin type | 1 |

By March, only seven were operational. The ready boats made patrols which were designed to show the Japanese that submarines were in the area, for Plotto says:

> ". . . General Kazbek asked me to be sure and show myself to the Japanese, so that they would know that if they attacked Vladivostok, they would be met by submarines. . . ."

Not more than nine of the fourteen became operational before the armistice, and the question of how much the Japanese feared these craft, this fleet in being, is questionable. Certainly their presence in the Far East had no effect on the outcome of the war. Torpedoes might have been used if they had not rusted into useless weapons because of their exposed position on the outside of the boat. But even this is doubtful, for the express mission of the boats was to patrol the coasts—not to engage in offensive maneuvers.

While the Vladivostok squadron was being assembled, the Naval Ministry was engaged in a futile attempt to purchase warships from the South American republics. Some means had to be found to increase the naval strength of the Empire, for it was becoming increasingly clear that naval strength was to be the decisive factor in the struggle with Japan. Since the construction of surface craft would take too long, it was decided that the offer made by Simon Lake, involving the construction of large submarines, was acceptable. Lake promised submarines capable of staying at sea in all kinds of weather, having great speed, large cruising radius, and strong armament.

The decision to accept this offer was not without merit. It was supposed that these submarines could be finished in time to be of assistance in the Far East. Further, because of the proposed cruising radius and ability to submerge, the boats could reach Vladivostok safely. This being possible, it was logical to assume that the boats could operate successfully, not only in the open sea, but along the Japanese coast as well. This assumption was based on the fact that anti-submarine warfare, as we know it today, was unheard of, and submarines were incapable of being blockaded. Since the boats were to be armed, the submarines could engage light enemy vessels on terms of relative equality, particularly since, with decks awash, they offered a small target, and had the protection of a water cushion for the hull. Then, too, fitted with the special diving compartment, or air lock, of the Lake design, this class would be able, unnoticed, to destroy enemy mine fields and cut communications between Japan and the mainland.

With all this, one fails to find any mention made of the possible use of the submarine as a commerce destroyer. While it is true that torpedo approach runs on a warship, or other vessel, necessitated firing from a range of only 300 yards, the relative impunity under which the submarine could operate against merchant shipping was completely overlooked. It remained for the Germans to bring the submarine to the fore as the primary weapon of offense against commercial shipping, and for the United States to prove that a relentless war against this type of shipping can reduce a nation dependent on the sea lanes for supplies to a state of impotency.

The outcome of the contract, let on April 1, 1905, for Simon Lake to build *Alligator, Drakon, Kaiman* and *Krokodil* in the Kreiton Yard in St. Petersburg, was an unhappy one, at least for the Russians. These boats were to have a displacement of 410/482 tons, a speed of 15 knots, cruising radius of 3500 miles, and were to be armed with four torpedo tubes, two 47-mm guns at the extremities of the conning tower, and four inches of armor. Acceptance was based on the requirement that the boats, without fuel replenishment, make the passage from Kronstadt to Port Said.

The results, as already mentioned, were unhappy. Mr. Lake's account [3] differs from the account given by Merhoushev, which is related, it is believed, for the first time:

". . . We must not forget that this was in the beginning of 1905. . . . It wasn't the fault of the Ministry that its proud dreams were destined not to be realized, but, rather, because of the lacks in the technical abilities of the times. Construction dragged on for all of five years, and, instead of underwater cruisers, the result was a number of worthless submarines which were unable to submerge and invariably stood on end, first by the bow, then by the stern. After long experiments, the American engineers, with Lake at the head, officially acknowleged their helplessness to assist and suggested to the Naval Ministry that it accept the boats as they were. On the spur of the moment the Ministry replied that it didn't need submarines which were unable to submerge, and that Lake could do with them what he wanted. The American decided to tow them to Sweden and to offer them to the Swedish Government at a reasonable price. The Ministry suddenly realized that three million rubles had been paid and that there remained the last payment in the amount of one million rubles. In addition, it was possible that the Swedes would succeed in making the boats submerge. Then the Swedish fleet, for an insignificant sum, would, immediately, be strengthened by four battle units. This, evidently, could not be condoned. . . ." [4]

The four boats involved were about twice the size of any submarine built previously. It is little wonder, therefore, that the Russian authorities settled on a course which led to the manning of the unfinished boats by Russian crews and sailing them from Kronstadt to Biorke, in Finland. Here a series of trials were conducted and it was found that previous troubles were caused by the fact that, somehow, the boats had been overloaded by a matter of some twelve tons.

Since it was imperative that the boats be lightened, the problem was to remove something—despite the fact that no superfluous weight was apparent. While the problem was being considered, the four boats were taken to Revel, late in the fall of 1910, where, in the course of the winter, they were rebuilt. Funds were forthcoming from the one million rubles owed, and unpaid to Lake and his associates. This fund was placed at the complete disposal of the individual commanders, to be used for making repairs required to make the boats operational. In order to cut through the usual governmental red-tape, the commanders were further authorized, in their own names, to give orders to private yards and plants, as well as to government plants.

The plan for the lightening of the boats, as finally developed, involved the removal of four of the engine cylinders and altering the foundations. It was anticipated that speed would be reduced by a knot and one-half, but since no other large weights existed, the sacrifice was considered satisfactory. Although the plan was opposed, in fact disapproved, by the Naval General Staff, the commanders reported that, acting upon their previous directives, the alteration had already been accomplished. This initiative and ability on the part of Russian submarine personnel is evident throughout the history of early submarine construction in Czarist Russia, and is, in fact borne out by Simon Lake himself, who noted that:

"I am somewhat puzzled by the reports of the apparent ineptitude of the Russians in dealing with mechanical matters. I found them excellent mechanics, for the most part, and in some things they were way ahead of us. . . ." [5]

At the time alterations were being accomplished, a ballast-compensation system was installed. Pumps, driven by the engines, pumped water into a tank in an amount equal to the petrol expended in engine operation. This system resulted in the ability to maintain any given condition of ballasting, or very nearly so. Submersion, as a result, was greatly accelerated.

As a further, and unexpected weight reduction, the 47-mm conning tower gun was discarded. The removal of the weapon was of little importance since train in azimuth was impossible and elevation was limited to some three degrees. Torpedo armament was, however, increased by two external, reversible tubes of the Dzhevetsky-Podgorny type, able to fire in traverse.

By the spring of 1911 the four boats could submerge in five minutes, causing no trouble in the process, and handling themselves well while submerged. Underwater speed exceeded the contract speed; 7½ knots instead of the six called for by the designers.

It cannot be denied that full credit for the successful alterations goes to the naval personnel concerned. The solution of a technical problem which had, apparently, baffled the designers, by those officers and men of the submarine service who had, after barely five years of work with submarines, been able to come up with an answer is refutation of the rather widespread belief that submarine work going on in Russia today is something new. Contrary to this belief, Russian shipyard workers have a long history of submarine work behind them and it is not impossible that workers in this field have remained and passed along to younger workers the knowledge accumulated over the years. And this despite the change in government.

The unhappy results of the Lake contract did not deter the Russians in their efforts to build the fleet up to war strength. Nor did the termination of the Russo-Japanese War cause cancellation of plans. In the spring of 1906, *Sterlyad*, of the Holland type, built in the Nevsky Yard, in St. Petersburg, was placed in service.

At this time the need for training loomed large. In order to establish a training program, there was formed a Training Division[6] with Rear Admiral Shchensnovich, appointed Chief of the Submarine Service on April 22, 1905, as first commander.

School was set up, in the fall of 1906, in an abandoned barracks. Once underway, training accelerated and the number of students, both officers and ratings, increased. But it was not until 1908 that training took any other form than that of practical work on the boats assigned to the Training Division. This was due, primarily, to the fact that there was no classroom program, as such, nor were there any teachers with sufficient experience to teach. Then, too, equipment was lacking.

In the spring of 1907, the Admiral was relieved by Commodore P. P. Levitsky, who had commanded the cruiser *Zhemchug* during the battle of Tsushima. Levitsky was a hard-working officer who took part in all phases of the training program, such as it was, and he began to make changes in an effort to establish a realistic training program.

The training program demanded that every officer know not only the arrangement plans of the submarines, but also be thoroughly familiar with handling the boats under all cruising conditions. A thorough knowledge of all machinery was mandatory and each officer was required to handle the boat independently. Student officers carried out the duties normally assigned to the ratings, such as controlling the vertical and horizontal rudders, standing watch at the electrical station, on the engines, air pumps, valves controlling the flooding and ballasting systems, etc. The care of the Whitehead torpedoes, and the procedure for loading the tubes, was

also part of the training program. There seems to be little question that training was thorough and that, while the older boats did not carry engineers, the officers and crews were able to handle their boats rather well.

Casualty drills were conducted and since every dive was an unknown quantity, officers and crews soon became accustomed to emergency conditions and reacted accordingly. As a result the crews had more than a nodding acquaintance with their specialties and the arrangements of their boats. In addition they became familiar with all maneuvers for the various conditions of cruising and displayed "personal initiative, sagacity, and resourcefulness."

The annual overhaul period, undertaken by the officers and crews, was superintended by these personnel so that the crews were able further to familiarize themselves with their machinery. The majority of the alterations and improvements were made on the initiative and under the direction of submarine personnel.

The diversity in training, as well as the stability of assignment to a certain boat, resulted in relatively good safety. Despite the rather primitive construction of the first submarines, four boats, *Delfin, Kambala, Forel,* and *Minova,* were all that were lost up to the first World War. Loss of life occurred in only two of the mishaps. This safety record compares favorably with that of other nations during the same period.

No attempt was made to draft men for submarine service. Both officers and men were volunteers, but few people had the necessary faith in the battle capacity of this comparatively new weapon, and very few officers volunteered despite a slightly higher pay rate in the lowest ranks. The feeling was expressed that "they wouldn't serve in steel coffins, much less in those which were submerged." Most of the volunteers returned to surface duty as soon as possible so there was no trained officer reserve to fall back on when new personnel were needed to man new boats.

The situation was much better with respect to enlisted personnel. Increased pay was an incentive, as were the faster promotions to petty officer rating. In addition, it was possible to earn overtime pay in an amount equal to 50 percent of the base pay for the rating.

In August, 1907, the operable submarines took part in their first maneuvers with the fleet. These maneuvers, in the Gulf of Finland, proved that the new weapon could operate with the fleet, within limits, and submarine participation led to further building, not only on government contract, but by private firms as well.

The Nevsky Shipbuilding Yard undertook the construction of *Sudak,* 105 tons, and won acceptance for its product. This boat, together with *Losos,* were shipped to Sevastopol by rail, and formed the nucleus of a Black Sea fleet.

In the fall of 1907, *Karp, Karas* and *Kambala* arrived in Libava. These boats had been built in Kiel, in the Germania-Werft Yard. They were manned by graduates of the Training Division and, in convoy with *Khabarovsk,* made the trip from Kiel to Libava without mishap.

The story of this order is a rather interesting one.

*Forel,* it will be recalled, was presented to Russia by Emperor Wilhelm II, of Germany. This boat, of 16 tons displacement, was the brainchild of a Frenchman, D'Ekville, who, since he was unable to interest the French Government in his plans, offered the same plans to Germany, which country, at the time, had no submarines. The German Naval Ministry agreed to finance the building of the all-electric, experimental *Forel,* which was to perish, ultimately, in the Vladivostok area during the Russo-Japanese War.

As a result of German generosity, Russia placed an order for *Karp, Karas,* and *Kambala,* which were three years abuilding. The delay is understandable when it is remembered that German shipyards lacked experience in submarine construction. However, the ironic tone of the accounts of this order stem from the fact that inexperience was not the only reason for the delay in completing the order. German interest in submarines was increasing, and here was an opportunity to experiment—with someone else's money. The boats were put through a series of tests which the Russians believed enabled the Germans to obtain all the data necessary for planning their first submarine which, as a result, was better than any the Russians had. "Thus, on Russian money, the Germans learned submarine cruising and, consequently, were able immediately to start the construction of a basic type, from which an underseas fleet was created which almost gave the victory to Germany in the war of 1914-18," is the way Merkoushev expressed the feeling in Russia.

In addition to the German-built boats, the Baltic Yard, in 1907, laid down *Minoga,* 123/144 tons, and *Akula,* 370/475 tons, built from plans developed the previous year by Bubnov. *Minoga* was accepted by the government at the end of 1909; *Akula* in the spring of 1911.

Late in the fall of 1907, supervision of all submarine affairs was transferred to the Department of the Chief Inspector of Torpedo Affairs, and a subsection, concerned only with submarines, was established under Commodore M. N. Beklemishev.

So engrossed were the Russians with submarine construction that any scheme which offered any hope of success was undertaken. An example of one such scheme was the construction, in Nikolaev, in 1908, of what was to be the first mine-laying submarine in the world—the 512/752-ton *Krab.* This boat, the project of one Naletov, was a dismal failure. The designer, a railroad engineer, had never before attempted the construction of a vessel, to say nothing of constructing a submarine. It was, therefore, little wonder that construction dragged on until the summer of 1915 and that, when the boat was finally operational, it became known as the "box of surprises." Although her personnel managed to eliminate most of the bugs, the experiment was hardly a success.

At the same time a Dzhevetsky-type submarine, built by popular subscription, was placed in service. This boat made use of petrol engines, not only for cruising on the surface, but underwater as well. Compressed air for engine use replaced the usual storage batteries, but little advantage was gained. The boat exhausted great gas bubbles which were visible at a great distance. This effort, named *Pochtovy,* was stricken from the records of the fleet in 1913.

In the spring of 1908, Russia became embroiled with Turkey, and took the occasion to move the German-built boats to Sevastopol, increasing the number of submarines in the Black Sea to five. *Karas, Karp* and *Kambala* were so constructed that the hulls could be taken apart and the individual sections could be shipped by rail. However, the connective flanges, together with the nuts and bolts used to hold the sections together, rusted very quickly and corrosion, caused by the salt water, was extensive. Consequently, the hulls were weak, so weak, in fact, that by the beginning of the first World War the commanders of the boats had orders not to submerge more than 60 feet.

On May, 1909, during a night practice attack on the squadron returning to Sevastopol, *Kambala,* running half submerged, was hit by the armored bow of the battleship *Rostislav* and was cut in two. She went down with her crew of twenty, and only one man, the commanding officer, who had been on

the upper deck of the submarine, was saved.

*Makrel* and *Okun,* Bubnov-type boats, of 140/177 tons, which had been in construction since 1904 in the Baltic Yard, were finally delivered in 1909, and then only after extensive alterations had been made.

Numerically the fleet gained nothing, for a year later *Forel,* while in tow of *Plotva,* was swamped by a wave and sunk in the Vladivostok area. The tiny craft was raised, but because it was considered to be useless for battle purposes it was not refitted, but was stricken from the fleet list.

Organizational work went along with construction and by the end of 1910 a Brigade of Submarines was formed in the Baltic Sea, under command of Rear Admiral P. P. Levitsky. This Brigade, within four years, was composed of two divisions, as follows:

1st Division—*Akula, Minoga, Makrel, Okun*

2nd Division—*Alligator, Drakon, Kaiman, Krokodil*

and the tenders *Khabarovsk* and *Yevropa.*

*Morzh, Tulen* and *Nerpa,* 630/784 tons, 16/12 knots, of the Bubnov-type, were laid down in Nikolaev in 1912, and in 1913 *Kit, Kashalot, Narval,* 621/750 tons, 16/12 knots, of the Holland-type, were put down. The Black Sea area thus became a submarine construction center and built the boats for use in that area, eliminating the need for transporting the hulls overland.

In the north, at the Putilov Wharfs, in St. Petersburg, the construction of the rescue ship *Volkhov* was begun. This 800-ton vessel, the forerunner of the ARS-type of modern vessel, was to be used especially for the raising of foundered submarines. It was modeled after the German *Vulcan,* and like it, consisted of two ships, joined at the bow and stern, between which the submarine was to be raised. Salvage pumps were installed, and cranes, capable of raising a submarine from a depth of 180-feet in about two hours, were also installed. Shops were provided and facilities for caring for injured persons were incorporated.

During 1913, disaster overtook *Minoga,* which sank with all hands during an experimental dive. Salvage was accomplished in twelve hours, however, and there were no casualties.

During the same year, the newly-constructed Noble-Lessner Yard, in Revel, laid down twelve submarines of the Bubnov type, of 650/784 tons, 18/-9.5 knots. The Baltic Yard, and its branch in Nikolaev, split an order for twelve boats between them.[7, 8]

These boats were not finished prior to the outbreak of the first World War, with the result that, at the beginning of the war, despite the great effort put forth on the development of a "silent service," Russia had, in the Baltic Sea, only one brigade of eight obsolete (1904-1906) submarines, of small displacement (123/144 to 410/482 tons) and slow speed (8 to 12 knots), equipped with worn out machinery and incapable of submerging in less than from three to five minutes. Oddly enough, it does not appear to have dawned on the crews of the boats that they would be called upon to man such obsolete weapons under wartime conditions. Yet, when war did come, these same boats were operated, and although they compiled no tonnage sunk records, their presence in the Baltic presented a threat to the Germans out of all proportion to their actual effectiveness.

Conditions were the same all around the coastal periphery of pre-World War I Russia. The Black Sea knew only *Losos, Sudak, Karp* and *Karas,* all obsolete and useful only for training purposes. Vladivostok harbored nine submarines, only four of which could be considered as even slightly effective.

To further complicate the situation, the Army Engineer's Corps, in 1912, took over the defense of Kronstadt Har-

bor, and decided to build a submarine fleet of its very own. The order was placed with the Nevsky Yard and consisted of three Holland-type submarines of 33/44 tons each. Ultimately the Naval Ministry was to inherit these craft, called by numbers the 1, 2, and 3, but only after their utter uselessness was apparent even to the Engineers. These boats were transported from place to place in the Gulfs of Finland and Riga, they made their appearance on the Danube and even in the White Sea, for what purpose has never been determined. Their fragility was apparent and their 50-hp. Diesel engines were very seldom operative. Batteries of the alkaline type had been installed but "were absolutely no good at all."

## WORLD WAR I

The outbreak of war, on July 18, 1914, found Russia in sad straits. While many orders had been placed, actual delivery was for some time in the future. Training, as was noted above, was somewhat better, but organization was in the development stage.

In fact it was not until just prior to the outbreak of actual hostilities, July 9, 1914, that Commodore A. V. Kolchak, Chief of the Operations Branch of the Staff of the Commander of Naval Forces, so much as visited the Brigade of Submarines in the Baltic. He sat as chairman of a committee, composed of the commanders and staff specialists assigned to submarines, whose purpose it was to consider ways and means of strengthening the fleet. The result of this meeting was the decision to construct, as rapidly as possible, *thirty* more submarines, in addition to those building. This decision, coming as it did at the outbreak of war, was never implemented, primarily because of the confusion generated by the hostilities.

During the winter of 1914-15, Admiral Rusin, Chief of the Naval General Staff, proposed that a program of submarine construction be inaugurated. Afloat personnel of the Baltic and Black Sea fleets were again called in, and agreement was reached on a program. A competition was announced, and the best plans submitted in answer were those drawn by Holland, for a 950-ton boat. The Italian firm, Fiat, submitted equally good plans for a 920-ton boat.

In addition, since it was considered necessary to develop a purely Russian type, the commission decided to order several submarines of the Bubnov design of 930-tons surface displacement. Bubnov's designs, for all their faults, were the best in the fleet at the time.

Late in the fall of 1915 the study of plans was concluded. In December, 1915, five Russian yards received orders for the construction of the first *seventy* submarines, some of which were required to be in service by the end of 1917, and some in early 1918.

Altogether this program called for 114 submarines, 112 to be standard types, and two to be experimental units. The decree covering this construction was promulgated in March, 1915, and stated that all construction was to be finished by 1920.

It was the hope of the planners that the 1912 building program would provide the needed units until the fruits of the 1915 program were ripe, at which time Russia felt that her submarine strength would be adequate to cope with any attacks from the sea areas which surrounded her.

The competition-winning Holland boat had the following characteristics:

| | |
|---|---|
| Displacement, surface.... | 950 tons |
| Displacement, submerged | 1200 tons |
| Length ..... | 250 feet |
| Beam ..... | 24 feet |
| Draught ..... | 11 feet |
| Speed, surface ..... | 16 knots |
| Speed, submerged ..... | 9 knots |

The plans, as drawn, called for the installation of four, 550-hp. Diesel engines, to be used for main drive on the surface and for driving the dynamos which were to furnish the motive power while submerged. Specifications required that the boats be capable of staying down and moving at a speed of at least 5 knots for not less than 100 miles. Not more than one minute was permitted for diving from a completely surfaced condition. Only twenty seconds was permitted for a dive from the awash position. Hull strength was to be such as to withstand pressures encountered at 300 feet. Three periscopes were to be installed in order to afford the maximum in visibility and maneuverability.

Armament was to include two 100-mm. guns, one 57-mm. anti-aircraft gun, and twelve torpedo tubes, eight of which were to be internal tubes, and four external tubes, of the reversible type as designed and improved by Dzhevetsky, Podgorny, and Levitsky.

Various improvements, determined as necessary from the experience gained in actual wartime operations, were to be incorporated. These improvements, as projected, are of interest because many of them, in greatly improved form, have been incorporated in modern submarines. For example, it was decided to install a means of permitting the boats to enter enemy minefields without becoming entangled in the mine anchor cables. Means were to be provided to avoid entanglement in whatever nets might be encountered at harbor entrances. Senior Lieutenant P. E. Stogov is credited with the design for a system of radio-telegraph which was to operate when the boat was completely submerged, regardless of depth. Unfortunately, no details are available, nor can it be determined whether tests were conclusive. Some means of underwater signaling was also contemplated. In recognition of the need for better living quarters during protracted submerged operations, crew's spaces were improved so as to make submarine life a little more pleasant.

Late in the fall of 1915, twelve submarines of the Holland type, of 350 tons displacement, arrived from the United States in disassembled form. Five of these were assigned to the Baltic, the remainder to the Sevastopol area. The Baltic boats were placed in service in the spring of 1916, but only two of the seven assigned to the Black Sea were in service prior to the outbreak of the Revolution.

This waste was caused by the complete breakdown of rail service in Russia. Never adequate, rail transportation was unable to cope with wartime needs, with the result that the Naval Ministry was unable to arrange transportation to the Black Sea for the remainder of the shipment.

It is well to remember that this account deals with the years of the first World War, at a time when sudden German superiority in the field of submarine construction was so marked as to cause wonderment that other, equally advanced nations, technically speaking, were so far behind in this field.

Russia, despite all her efforts, was no exception. Although the possessor of a submarine fleet, Russian submarines were not, in any sense, modern vessels. In fact, the description of the most modern boats, contained in a Soviet book,[9] is worthy of note. The book is based on an unfinished manuscript by the historian of the Russian Imperial Navy, V. A. Merkushov, titled *Submarines in the World War*. Tomashevich, in his foreword, notes that he used the manuscript ". . . in view of the fact that there is little data in the archival documents concerning the activity of submarines at the beginning of the war . . ." It may, therefore, be assumed that the facts, as published in 1939, are reasonably accurate.

*Akula* was the newest and best of the boats. It could remain at sea for about

two weeks, Fuel storage was sufficient to give the boat a cruising radius of about 1000 miles on the surface, with both Diesel engines in operation. However, no storage was provided for lubricating oil, space having been given to spare torpedo stowage. The Diesel engines lacked mufflers, with the result that the presence of the boat could be detected at great distances. *Akula* appears to have been grounded during her first battle cruise and the damage caused to her rudder and one shaft restricted her operations. In fact, *Akula* could not submerge but was continued in use until she was lost on patrol late in 1915, cause unknown. This submarine is credited with having engaged in a total of five attacks on enemy vessels, during which ten torpedoes were launched, with no hits being recorded.

*Minoga,* also fitted with Diesel engines, was capable of rather lengthy cruises, but because of her size, a mere 120 tons, was virtually unlivable for extended periods of time. Although the boat was fitted with two bow tubes, it was impossible to fire both of them simultaneously because trim could not be maintained.

*Makrel* and *Okun* encountered continual difficulties with their engines. Each had but one engine, driving a dynamo. It is obvious that any engine trouble resulted in loss of propulsion. This fact, together with their small size, 150 tons, made them very unseaworthy. Coupled with these factors was the unreliability of the horizontal rudders, which broke down at frequent intervals. These two were usually sent to sea in tow of the tender, evidently in order to conserve engine use, and in the hope that they would manage to return to base under their own power. Despite all their shortcomings, *Okun* at least is credited with having made eleven attacks during which six torpedoes were launched.

*Alligator, Drakon, Kaiman* and *Krokodil* never became seaworthy. The hulls were sheathed with wooden bars 15-cm. thick. The decks were also of wood, 7.5-cm. thick. The wooden bars on the hull were sheathed with galvanized iron. In the summer months, if the boats were not submerged at frequent intervals, the wood dried out and warped. During periods of frequent and protracted submersion, the wood swelled and twisted. The result of this frequent working of the bars was the development of leaks in the superstructure, so that when the weather made up cruising became extremely hazardous. Nevertheless, *Drakon* participated in six attacks and fired twelve torpedoes. *Alligator* was close behind, but *Kaiman* and *Krokodil* were of little use.

Everything being equal, the fighting qualities of the boats appear to have been determined by the aggressiveness of the commanding officers, and in view of the historical data, the courage and ability of the men who manned these boats was of the highest order.

Added to the hazards of going to sea in these submarines was the fact that buoyancy was destroyed by the adsorption of water by the wooden construction. Too, the hulls were weak, limiting submersion to about 90 feet. The draught, 16 feet, hampered the boats when shallow harbors were encountered. The gasoline motors were a source of constant mechanical trouble and since they used up the oxygen in the boats, personnel were in danger of suffocation.

It is little wonder that the planners attempted to incorporate in the new designs all the changes and improvements which were noted in the plans drawn by Holland and Fiat.

By 1916, as the boats ordered in 1912 began to come off the ways, a new program for submarine construction was delineated. Envisioned were "submarine cruisers," of 2000 tons displacement. Just what led to the decision to build such large submarines, particularly in view of the penchant for

small coastal types up to this time, is not clear. Nevertheless competition was announced and the Noble-Lessner Yard in Revel and the Baltic Yard, a State yard, submitted plans. It was difficult for the commission to decide between the two sets of plans, so the decision was to let each plant build one boat, and after trials had been completed to settle on the mass production of the better boat. The order to begin construction was issued on December 9, 1916.

The plans, as submitted, showed the following characteristics:

| | |
|---|---|
| Displacement, surface .. | 2,000 tons |
| Displacement, submerged | 3,000 tons |
| Length ..... | 328 feet |
| Beam ..... | 31 feet |
| Draught ..... | 13 feet |
| Speed, surfaced ..... | 20 knots |
| Speed, submerged .... | 10 knots |
| Speed of submersion: | |
| From fully surfaced.. | 1 minute |
| From awash .....15-20 seconds | |

Propulsion was to be obtained from two 2000-hp. Diesel engines connected directly to the shafts. Two other Diesels, each of 1350-hp., were to be used to drive the dynamos, which were to provide current for two electric motors, each of 800-hp., to be used during submerged periods. Fuel capacity was to be 150 tons. Two of the main ballast tanks were to be so fitted as to serve as additional fuel tanks, doubling capacity, and giving the boats a surfaced cruising radius of up to 12,000 miles. Submerged radius was estimated at 150 miles at five knots and 200 miles at three knots. The hull was to be subdivided by watertight bulkheads and fitted with triple bottoms so that in the event of a mine explosion, not more than 25 tons of water would enter the hull.

Armament was to include four 100-mm. guns, installed in pairs, fore and aft of the conning tower, and two 57-mm. anti-aircraft guns. It was planned that the torpedo tube installation would total nineteen. Thirteen were to be internal, four in the bow, three in the stern, six traversing in sets of three to a side. Six were to be external, three on a side, of the reversible Dzhevetsky, Podgorny, Levitsky type.

While this planning was going on the war situation created more and greater problems for the Navy. One of these problems was concerned with the necessity for developing some means of hampering the movement of German vessels in the Baltic. While England had sent some submarines into the Baltic, and while these boats enjoyed more success than the Russian boats, the results were negligible. It was realized that mining operations were necessary and, as a means of accomplishing these operations, alterations were made to *Yersh* and *Forel,* under construction in the Baltic Yard, in order to convert them into submarine mine layers. By the summer of 1917, during trials in Revel, *Yersh* proved, according to the standards of the times, to be in excellent shape. "Her battle qualities were so high that she had no equal, at that time, in any of the foreign fleets," is the somewhat over-enthusiastic way in which Merkushev expressed his feelings.

This event was, however, in the future. In 1916 the urgency was great and a contract, calling for the construction of 235-ton mine layers, was let to the Baltic Yard. These boats were to carry from 16 to 20 mines and were to be ready by July, 1917, an elapsed building time of seven months.

One final contract, springing from the same need, was contemplated. Once again the afloat personnel were called upon, this time to assist in the development of plans for large mine layers, capable of carrying 150 mines within the pressure hull so they might be serviced and inspected inside the boat. While these boats never got beyond the drawing board stage, their characteristics are interesting because of their

size and great cruising radius, plus the fact that the limitations imposed by smaller sized submarines had begun to impress themselves on the planners. It must have been apparent to the Russians that German U-boats could accomplish missions never before thought of and that larger boats, with greater cruising, were required. What the people going to sea in submarines thought they needed was a boat something like this:

| | |
|---|---|
| Displacement, surface... | 1,700 tons |
| Displacement, submerged | 2,600 tons |
| Length ..... | 300 feet |
| Beam ..... | 30 feet |
| Draught ..... | 12 feet |
| Speed, surfaced ..... | 15 knots |
| Speed, submerged ..... | 9 knots |
| Cruising radius, surfaced | 7,000 miles |

Once again provision was to be made for conversion of part of the ballast system into fuel stowage in order to increase the cruising radius. Submerged, the mine layer was to cruise 150 miles at five knots, and 300 miles at three knots. In addition to its cargo of mines, the boat was to carry two 100-mm. guns, one 57-mm. anti-aircraft gun, and was to be fitted with but three torpedo tubes, two forward and one aft.

All these plans, had they been fulfilled, would have found Russia with a completely new fleet of submarines aggregating more than 100,000 tons. At the outbreak of the Revolution, however, Russia could muster but forty submarines, only eighteen of which could be considered useful for war purposes. These were the results of the building program initiated in 1912, and they arrived in the fleet between 1915 and 1917, at a time when the conditions within Russia were such as to nullify whatever use they might have been had they been completed according to schedule.

## DEATH OF A FLEET

The unrest within Russia was felt throughout the fleet, but the submarine arm campaigned until the end. In 1917 the new submarines *Bars, Lvitsa,* and one unidentified boat disappeared. *Bars* was lost in the Baltic, as was *Lvitsa.* The English E-19, cruising in the same area, came upon a torpedo without a warhead. The serial number identified it as having belonged to *Lvitsa.* During recovery of the torpedo, E-19 was subjected to an attack by an enemy submarine and almost became a victim herself. It was presumed that all three boats had been victims of this type of attack, particularly in view of the superior skill displayed by German submarine commanders during the war.

When, on March 21, 1918, the German fleet appeared off Gange and put a landing force ashore, the Russians had to destroy four of their boats. *Orlan, Gagara, Kit, Kashalot, Narval, Krab, Skat, Nalim,* and one unnamed submarine were taken out to sea and were blown up and sunk in deep water about two miles from the Konstantinovsky Battery in Sevastopol. *Karp, Karas, Losos* and *Sudak* were disposed of in a similar manner in the Severny Roadstead. After the fall of the Crimea, and after General Vrangel's army had been liquidated, the remaining units of the Black Sea fleet were taken to Bizerte. Among the units were the submarines *Burevestnik, Tulen* and *Utka.*

When the work of destruction and evacuation was over, the triumphant Bolsheviks were left with but three captured submarines, and a heritage of submarine construction dating back to 1850. The submarines were of little value, but the heritage of construction work in submarines was to prove invaluable once the new regime decided to undertake a program which, by the

beginning of the second World War, was to find Russia well in the van in this field.

As one reads the accounts written by the men who participated in the planning and development of submarines in Russia during the first seventeen years of this century, one is impressed with the fierce loyalty to a dream, the dream of superiority in that naval branch encompassing the "silent service," which always has, in whatever the country, served with pride and distinction the needs of the country. In spite of the dread in which submarine fleets are held, all are unanimous in their admiration for the men who sail in them and who have perished with them.

## References


1. The author, for historical matter, has drawn upon Alan H. Burgoyne, *Submarine Navigation, Past and Present,* London and New York, E. P. Dutton & Co., 1903, Vols. I and II, excerpts from which are used with the permission of the publishers.
2. Present day transliteration, in accordance with the method employed by the American Council of Learned Societies, would indicate that the latter is more nearly correct, and hence will be used.
3. *Submarine,* The Autobiography of Simon Lake, as told to Herbert Corey, D. Appleton-Century Co., Inc., New York, 1938, pp. 93 *ff.*
4. Original in the old Russian orthography. Translation by author.
5. *Submarine, op. cit.,* p. 200.
6. Consisting of *Sig* (Lake type), *Peskar, Beluga, Sterlyad, Losos* (Holland type), and the tender *Khabarovsk.*
7. Baltic Yard—*Bars, Gepard, Vepr, Volk, Yaguar, Kuguar, Rys, Lvitsa, Leopard, Tur, Pantera, Tigr, Yersh, Zmeya, Forel, Yaz, Uzh, Yedinorog.*
8. Nikolaev Yard—*Orlan, Burevestnik, Utka, Gagara, Pelikan, Lebed.*
9. A. V. Tomashevich, *Podvodnie Lodki v Operatsiyakh Russkova Flota na Baltiiskom More v 1914-1915 gg* (Submarines in the Operations of the Russian Fleet in the Baltic Sea in 1914-1915), *Voenmorizdat, Moskva-Leningrad,* 1939, Vol. I. (The second volume, to the best of the author's knowledge, is not available in the United States and may never have been published.)

# TWO NEW ECONOMICAL COMPUTERS FOR THE DESIGN AND ANALYSIS OF SERVOMECHANISMS, NETWORKS, AMPLIFIERS, AND ANALOGOUS DYNAMICAL SYSTEMS

DONALD HERR, HONORARY MEMBER

THE AUTHOR

MR. HERR, Honorary Member of the A.S.N.E., has the B.S. in E.E., M.S. in E.E., and E.E. degrees. He was National Coffin Foundation Fellow of the General Electric Company, National Tau Beta Pi Fellow, and National Sigma Tau Fellow at the Moore School of Electrical Engineering, University of Pennsylvania, and at M.I.T., prior to World War II. He was also awarded a National Gordon McKay Fellowship by Harvard University and received the A. Atwater Kent Award in Electrical Engineering from the University of Pennsylvania. A licensed radio amateur at 12, Mr. Herr first worked summers at RCA and Bell Laboratories and was with the General Electric Company in 1939 and 1940 as development engineer before volunteering for over five years of active Naval duty. He served as Officer-in-Charge, Electrical Minesweeping Group, Bureau of Ships, December 1940 to April 1943; as Acting Design Superintendent and Officer-in-Charge, Los Angeles-Long Beach Harbor Surge Investigation, U. S. Naval Shipyard, Terminal Island, to November 1944; and as Research-Patents Liaison Officer, Office of Naval Research, to January 1946, returning to inactive duty as lieutenant commander, U.S.N.R. Mr. Herr received two Navy letters of commendation. Since 1946, he was assistant to vice president, in charge of the engineering division of Control Instrument Company, Brooklyn, New York, and is project engineer at the Reeves Instrument Corporation, responsible for new servo and computer component developments. Mr. Herr has been associated with Dean Harold Pender and Professor Ernst Guillemin in advanced network theory and has specialized for 12 years in development and design of servomechanisms, differential analyzers, computers and fire control systems, utilizing advanced network analysis and synthesis methods. He has contributed frequently to the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS and was the Society's 1945 Prize Essayist on the subject: "Engineering in the Navy as seen by an Active Reserve Officer." He is senior member of the I.R.E., member of the A.I.E.E., A.S.M.E., American Mathematics and Physical Societies, New York Academy of Sciences and Sigma Xi, and appears in "American Men of Science."

## I. INTRODUCTION

An extensive bibliography exists of the great variety of analogue computers for the solution of ordinary differential equations or algebraic equations. Many such computers are of such large initial cost, size, or relatively fixed location as to not make them conveniently available to many systems designers. Also, many such computers are designed for the solution of special or fixed forms of differential or algebraic equations and often lack the degree of precision or reliability required for a practical design solution largely because of inherent inaccuracies of the computing components employed.

The REAC,[1] a flexible electronic, analyzer, has already proved its great usefulness in the design and study of systems which can be defined in terms of ordinary differential equations. The author and a former colleague have described [2] the use of the REAC in modern servo design problems. Twelve years ago the author also described [3] the design and operation of a flexible, electrical, analogue algebraic-equation solver for use in the design and study of linear systems in terms of their characteristic algebraic equations.

It is the purpose of this paper to describe two new economical analogue computers to be used as *desk-side tools* in the design and analysis of servomechanisms, networks, amplifiers, and analogous systems. In a certain sense the two computers described herein are complementary in their use and with the use of a differential analyzer.

The first computer presented herein is actually a modern version of the algebraic-equation solver earlier described.[3] The second computer presented in this paper is a mechanization of the "locus of roots" method of analysis and design previously explained by W. R. Evans.[4] Each of these two new computers uses two new computer components. One new component is a high-precision, universal-frequency a.c. induction resolver.[5, 6, 7] The other new computer component is an a.c. induction potentiometer.[7, 8]

Although the analysis and design problems of servomechanisms, networks, and amplifiers have motivated the two computers described herein, analogous problems arising from dynamically analogous physical systems will suggest themselves for solution by these means.

It seems in order to begin from the beginning. Excellent references are available[9, 10, 11, 12] for the proper understanding of the mathematical and physical fundamentals of the systems involved. The behavior of linear systems may be described entirely in terms of functions of the complex frequency variable, s, depicted in Figure 1. The complex frequency variable, s, is defined by

$$s = \sigma + j\omega = |s| \angle \theta \qquad (1)$$

where $\omega$ is the real frequency variable and $\sigma$ is the real part of the complex frequency variable. The "s-plane," or the "complex frequency plane," is depicted in Figure 1. It is apparent that as a point moves along the positive imaginary axis of Figure 1 from the origin to infinity, the real frequency varies from zero to infinity. It is further apparent that a function of the form

$$e^{st} = e^{\sigma t}\, e^{j\omega t} = e^{\sigma t}[\cos \omega t + j \sin \omega t] \qquad (2)$$

represents a "cisoidal oscillation" [13] with exponential envelope in time. Since $\omega$ and $\sigma$ are each defined as (positive or negative) reals, $\sigma$ is in the nature of a "damping factor." Hence, a point in the complex s-plane represents a certain combination of damping (the real part of s) and real frequency

[1] See "V. Bibliography" at end of paper for all references.

$$M(s) = \frac{\theta_o}{\theta_i}(s) = \frac{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0}{b_m s^m + b_{m-1} s^{m-1} + \cdots + b_0} = \frac{N(s)}{D(s)}$$

Roots of D(s) have negative real parts for stability

FIGURE 1—Complex Frequency Plane and a Typical Ratio of Functions of a Complex Frequency

of oscillation (the imaginary part of s). It is evident that negative values of $\sigma$ correspond to exponential envelopes which decrease as time increases, while positive values of $\sigma$ denote increasing amplitude of envelope with time. If physical systems did not "saturate," i.e., become non-linear, such an exponentially increasing with time behavior would result in ultimate destruction. A zero value of $\sigma$ and a non-zero value of $\omega$ represents a sinusoidal oscillation of constant amplitude and frequency $\omega$. While positive values of $\omega$ correspond to real frequencies, negative values of $\omega$ represent the frequency domain mathematically symmetrical thereto; hence the complex frequency variable, s, is defined over the entire s-plane by paired values of $\sigma$ and $\omega$.

A wide variety of linear dynamical systems may be described in terms of their behavior as a function of the

$$A(s) = \frac{\theta_o}{\theta_i}(s) = \frac{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0}{b_m s^m + b_{m-1} s^{m-1} + \cdots + (b_n - a_n) s^n + (b_{n-1} - a_{n-1}) s^{n-1} \cdots + (b_1 - a_1) s + (b_0 - a_0)} =$$

$$= \frac{N(s)}{D(s) - N(s)}$$

For 1st Order Pole in A(o): $a_0 = b_0$ — 6 db/octave; phase - $\pi/2$

For 2nd Order Pole in A(o): $a_0 = b_0, a_1 = b_1$ — 12 db/octave; phase - $\pi$

For 3rd Order Pole in A(o): $a_0 = b_0, a_1 = b_1, a_2 = b_2$ — 18 db/octave; phase - $3\pi/2$

etc.

For 1st Order Zero in A($\infty$): $m = n+1$ — 6 db/octave; phase $(-\pi/2)$

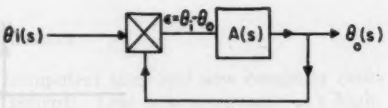
For 2nd Order Zero in A($\infty$): $m = n+2$ — 12 db/octave; phase - $\pi$

For 3rd Order Zero in A($\infty$): $m = n+3$ — 18 db/octave; phase - $3\pi/2$

etc.

FIGURE 2—Another Typical Ratio of Functions of the Complex Frequency

complex frequency variable, s. This may be the driving-point impedance (admittance) function of a two-terminal network, driving-point and transfer impedance (admittance) functions of an n-terminal network, the open or closed "loop-gain functions" of a servomechanism or feedback amplifier, or of dynamically analogous systems. The computers described herein are useful in solving certain problems of analysis and design of linear systems which are adequately described by rational algebraic functions of the complex frequency variable s. For example, as depicted in Figure 1, in a certain transfer function, M(s), the ratio of the output to the input in the steady-state may be represented by a ratio of two rational algebraic functions of the complex frequency variable, s. Likewise in Figure 2, the so-called open-loop transfer function of the box labelled A in Figure 3 may be represented in the steady state by a ratio of two polynomials in the complex frequency variable, s. In each case it is evident that these functions or polynomials in the complex variable, s, are themselves complex functions. In Figure 4 a particular form of s is exhibited, namely, $s = j\omega$; this corresponds to the steady state behavior as a function of the real frequency $\omega$. The response of such linear physical systems, both in the steady state at real frequencies, and as a function of time, may be completely determined in terms of the distribution throughout the s-plane of the "zeros" in numerator and denominator polynominals such as depicted in Figures 1 and 2.

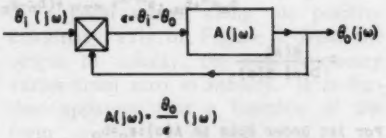



$$M(s) = \frac{\theta_o}{\theta_i}(s) = \frac{A(s)}{1+A(s)}$$

$$A(s) = \frac{\theta_o}{\epsilon}(s)$$

FIGURE 3—System Diagram Corresponding to the Functions of Figures 1 and 2

The two computers described in this paper are useful tools to predict performance of systems or components undergoing analysis or design before they physically exist and to facilitate intelligent decisions concerning design parameters in order to fulfill prescribed performance requirements. In a certain sense they also make it possible to design a simplest system fulfilling prescribed performance requirements within certain tolerances. Naturally, the usual precautions concerning "linearization" of the actual system to make it amenable of linear analysis, must be carefully observed. By extension, it is possible to introduce into the computer certain useful variations in the design parameters to determine limits of performance or limits of allowed variation in those parameters.




$$A(j\omega) = \frac{\theta_o}{\epsilon}(j\omega)$$

FIGURE 4—The Loop-Gain Function of Real Frequency

## II. A NEW ELECTRICAL ALGEBRAIC EQUATION SOLVER

With reference to functions involving the ratios of polynomials, such as depicted in Figures 1 and 2, it is well known that in order for the physical systems corresponding thereto to be "stable" the zeros of the denominator polynomial (the roots of the equation obtained by equating the denominator polynomial to zero) must have negative real parts. For example, if a certain denominator polynomial equation

$$D(s) = O \qquad (3)$$

have as its roots, $s_1 = \alpha_1 + j\beta_1$, $s_2 = \alpha_2 + j\beta_2$, etc., the requirement for stability of the corresponding system is that all the $\alpha$'s be negative. It is entirely possible to determine the negativeness of the real parts of the roots of the so-called determinantal equation, Equation (3), by application of the Routh-Hurwitz criterion to the coefficients in the equation without solving explicitly for the roots. In many cases, however, the information needed for adequate analysis and design goes beyond that possible to obtain by application of the Routh-Hurwitz criterion involving merely the coefficients of $D(s) = O$. In particular the entire behavior of $D(s)$, as a complex function of the complex variable, s, is needed. Furthermore, the ratio $N(s)/D(s)$ as a function of s is necessary and provides useful information in the design and analysis of physical dynamical systems, with and without feedback.

Let $P(s)$ denote any such polynomial in the complex frequency variable, s, and refer to Figure 5. Here, the coefficients $a_n$, $a_{n-1}$, $a_{n-2}$, . . . . . $a_0$ may be complex coefficients. In any case $P(s)$ is itself a complex function of the complex variable and has a real part, $R(s)$, and an imaginary part, $I(s)$, each of them real functions of the complex variable s. It is desired, with a fixed set of coefficients, $a_n$, $a_{n-1}$, etc., to observe the behavior of $P(s)$ on the complex P-plane as the complex variable s is appropriately varied in the complex s-plane. Figure 5 depicts such an algebraic equation solver or, more generally, polynomial plotter. This mechanization of equation 2 of Figure 5 is made possible by the existence of the new high-precision, high signal-to-noise ratio a.c. induction resolver already referenced.[5, 6, 7] The symbol for such resolver is given at the bottom of Figure 5. In this application only one of the two stator windings, space-phased 90° geometrical with respect to one another, is excited. This excitation is depicted by the arrow external to the circle symbol in Figure 5. The two arrows proceeding outwards through the circle symbol from two internal dots denote the two separate rotor winding outputs of a single resolver. These rotor windings are space-phased on the rotor structure 90° geometric. If $\Upsilon$ denote the mechanical rotation of the rotor of a resolver with respect to its stator in terms of a reference angle position, then one rotor winding will ideally develop an open-circuit voltage proportional to the stator voltage excitation and varying as the sine of the angle of rotation $\Upsilon$; the other rotor winding will develop an open-circuit voltage proportional to the cosine of the angle of rotation $\Upsilon$. If the stator winding of the kth resolver is excited with an a.c. voltage of appropriate time frequency and of RMS value $|a_k| \angle\psi_k |s|^k$, and if the rotor with respect to the stator is rotated through an angle $k\gamma$ then, ideally, the two rotor winding open-circuit voltage-outputs will be respectively

$$\left.\begin{aligned} e_{r1} &= |a_k| \angle\psi_k |s|^k \cos k\gamma \\ e_{r2} &= |a_k| \angle\psi_k |s|^k \sin k\gamma \end{aligned}\right\} \qquad (4)$$

It is seen that these two voltages are exactly the typical real and imaginary components in the term-by-term representation of the complex function $P(s)$

$s = \sigma + j\omega = |s| \angle \gamma$ ; a's REAL OR COMPLEX; IN GENERAL, $a_K = |a_K| \angle \psi_K$

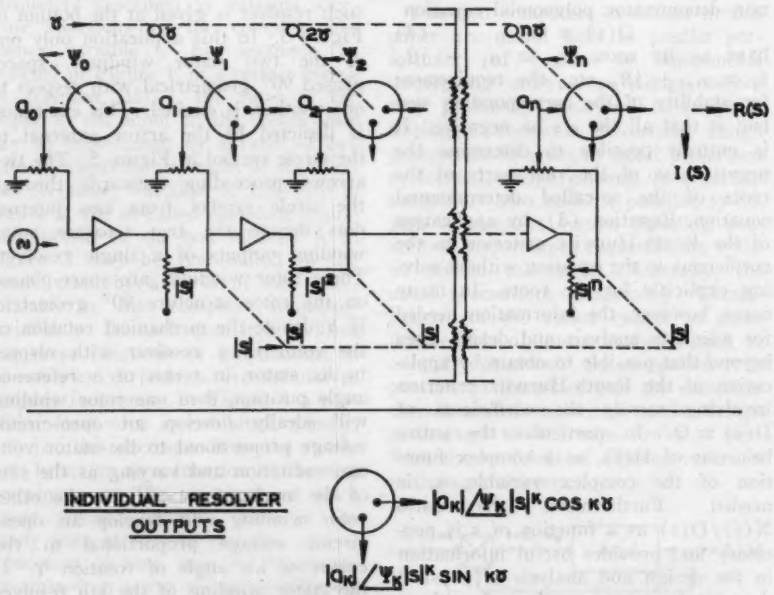
(1) $a_n s^n + a_{n-1} s^{n-1} + a_{n-2} s^{n-2} + \cdots + a_0 = P(s)$

(2) $a_n |s|^n \cos n\gamma + \cdots + a_1 |s| \cos \gamma + a_0$

$j[a_n |s|^n \sin n\gamma + \cdots + a_1 |s| \sin \gamma] = P(s)$

(3) $P(s) =$ REAL PART OF $P(s) +$ IMAG. PART OF $P(s) = R(s) + jI(s)$

(4) $P(s) = \sqrt{R^2(s) + I^2(s)} \quad \angle \tan^{-1} \frac{I(s)}{R(s)}$




INDIVIDUAL RESOLVER OUTPUTS




FIGURE 5—Schematic and Nomenclature for the Algebraic Equation Solver or Polynomial Plotter

of the complex variable s, given by equation 2 of Figure 5. It is evident also that by connecting in series the corresponding "real component" rotor voltages of all the resolvers, then a voltage representative of the real part, R(s), of the complex function, P(s), will be obtained; similarly, by connecting in series all of the second rotor windings of the resolvers, a voltage representative of I(s), the imaginary part of P(s), will be obtained.

In order to establish this complete electrical analogue of P(s) the electromechanical arrangement depicted in Figure 5 is used. The resolver to which is applied an excitation voltage proportional to $a_o$, the constant term of P(s), has its rotor locked in position in space. This position establishes the zero reference angle for $\gamma$, the phase angle of the complex variable s, defined in Equation (1). The resolver which is excited by a voltage proportional to

$a_1$, has its rotor mechanically geared to each of the rotors of all the succeeding resolvers, through integral gear multipliers. For example, as the rotor of resolver 1 goes through the angle $\gamma$, the rotor of resolver 2 goes through the angle $2\gamma$, the rotor of resolver 3 goes through the angle $3\gamma$, and the rotor of the nth resolver goes through an angle $n\gamma$. If any of the coefficients of the polynomial P(s) are complex then the stator of the corresponding resolver is rotated through an angle $\psi_k$ corresponding to the phase angle of the complex coefficient, as given in the first line of Figure 5. An easier way to do this practically is to introduce mechanical differentials in each of the mechanical drives to the rotor shafts such that the angles $\psi_k$ may be cranked in and locked, thereby making it possible to leave the stators of the resolvers, and hence the mountings of the resolvers, fixed in space. In general, however, if the coefficients of the powers of s in the polynomial P(s) are real coefficients the amplitudes of the coefficients $a_k$ are adjusted by settings on the coefficient potentiometers as depicted in Figure 5.

The powers of |s| are developed by a cascade of isolation amplifiers and linear potentiometers, with the latter all driven from the same shaft whose rotation represents the variable |s|. Then, as the phase angle, $\gamma$, of the complex variable, s, continuously rotates through increasing angle, |s| increases continuously at an appropriate rate from zero to unity per-unit value. In effect, the behavior of the complex function P(s) of the complex variable s is developed for all s values lying within the unit circle on the s-plane. It is evident that two applications of the polynomial P(s) to the machine are necessary and sufficient to determine the behavior of P(s) for all values of s in the s-plane, both within and outside the unit circle in the s-plane. The second application required merely involves inverting the order of the coefficients in application to the equation solver or polynomial plotter; essentially this second application solves for reciprocal values of the roots and hence the second set of zeroes must be reciprocated in magnitude and the phase angles reversed in order to obtain the corresponding s-values.

A zero of the polynomial P(s), that is, that value of s which makes P(s) zero, will be denoted by simultaneous occurrence of R(s) and I(s) both zero, within the noise and accuracy limits of the connected computer components. For this reason resolvers of maximum functional error not greater than 0.05 of 1% and signal-to-noise ratio in terms of maximum excitation of not less than 5000 are desirable. Furthermore, the coefficient potentiometers and the |s| potentiometers should preferably be of the continuous, non-granular, non-wirewound type. Further, it is desirable that a suitable electrical time frequency of the system be employed. It should be one most consistent with resolver and potentiometer stability, least noise, and maximum excitation. The referenced resolver and potentiometer exhibit optimum performance in the neighborhood of 400 cps carrier frequency. Furthermore, these devices are most easily "compensated" in the neighborhood of this frequency, and this frequency is not sufficiently great to introduce circuit capacity effects contributing to the noise level or instability of the system.

The two components of P(s) may be depicted on a long persistence oscilloscope screen or, through servomechanisms, may drive a pen in a rectangular coordinate tracking system, thereby making it possible to obtain a permanent record of P(s) on the P-plane as s scans the s-plane. Alternatively, through the use of one additional resolver and two servo drives, P(s) may be plotted in the P-plane in polar coordinates as depicted in Figure 6.

It is observed that Figures 1 and 2 illustrate the fact that steady-state

transfer-functions involve the ratio of two polynomials each of the nature of P(s). By the use of the additional equipment shown in Figure 7 the continuous quotient of the amplitudes of two such polynomials and the continuous difference of the phase angles of two such polynomials may be obtained. It is, of course, evident that the operation of the dividing servo will be restricted to a certain value of the quotient but by the use of changing scale factors the quotient may be explored closer and closer to a zero of the denominator polynomial. In Figure 7 the symbology for the potentiometers used to form the continuous difference in phase angles is a single circle with one internal dot and one external arrow. The notation for the summing amplifier, the servo amplifiers, and the servo motors is considered obvious.

It may be required that a transfer function approximate certain prescribed characteristics as a function of real frequency $\omega$.[14] In this case, $\gamma$, the phase angle of the complex variable s, is locked at $\pi/2$, in each of the two computers of the type depicted in Figure 5. $|s|$ then is made to increase continuously from zero along the real frequency axis on the s-plane. By comparison of computed $|Q|$ and $\Phi$ with the prescribed $|Q|$ and $\Phi$ functions of s the numerator and denominator polynomials may be varied in form and degree and the coefficients thereof adjusted to experimentally determine the simplest form of numerator and denominator polynomials, and the coefficient settings thereof, to approximate the required functions within specified tolerances.

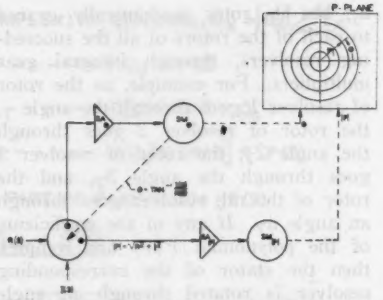


FIGURE 6—Extension to the Polynomial Plotter for Polar Representation of the Polynomial

Many other uses of the single and double polynominal plotter will be evident to the analyst and designer in his particular field.

## III. A LOCUS-OF-ROOTS COMPUTER

In the preceding section it was pointed out that two of the many uses of the electrical algebraic equation solver were to provide knowledge of the behavior of the functions of a complex variable defining the physical system and, specifically, to elicit the roots of the determinantal equation of such a system. The roots of a determinantal equation of a physical system find direct use in the time-description of the behavior of the physical system under specified initial conditions.

A very important kind of physical system is symbolically depicted in the block diagrams of Figure 8. Obviously both the systems there depicted are "feedback systems." The upper diagram of Figure 8 discloses a simple feedback system in which the signal fed back from the output to the input is on a one-to-one basis. In the lower diagram of Figure 8 the intelligence is fed back from the output to the input modified by the transfer function $A_2$ of the feedback path.

It is apparent, of course, that either A in the upper diagram of Figure 8, or $A_1$ or $A_2$ in the lower diagram of Figure 8, may themselves contain in-

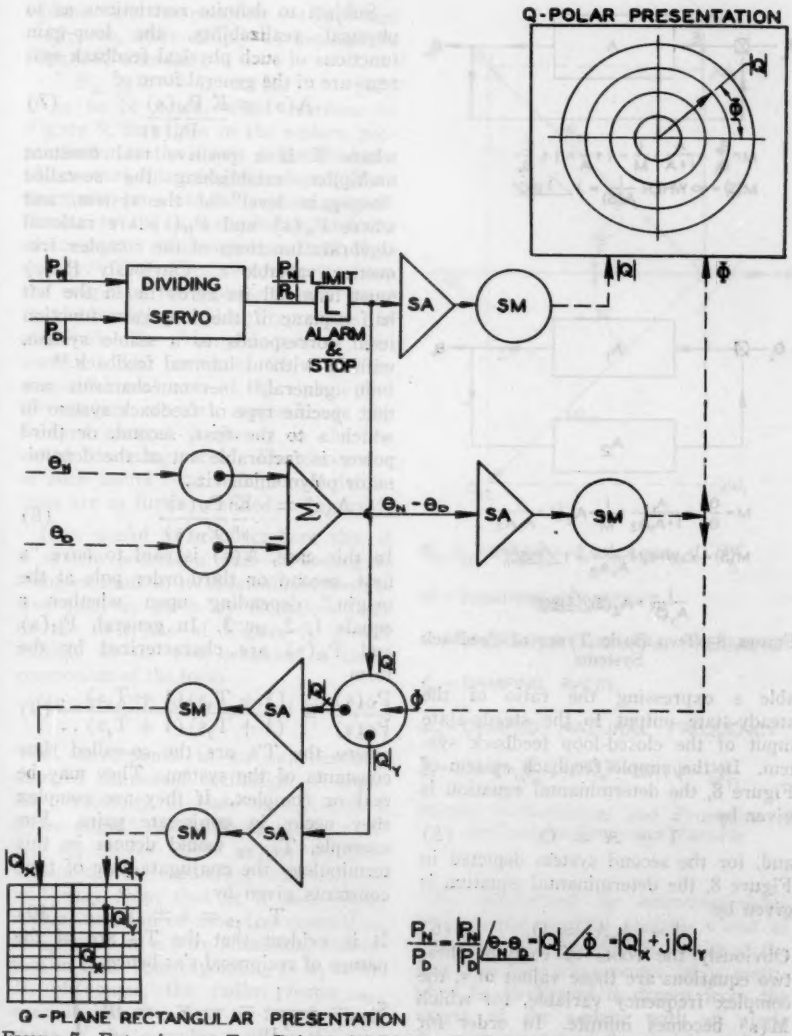



FIGURE 7—Extensions to Two Polynomial Plotters for the Continuous Representation of Their Ratio in Polar or Rectangular Coordinates

ternal feedback paths. For purposes of dissertation, it is assumed here that A, $A_1$, and $A_2$ are themselves stable systems. In the upper diagram of Figure 8, A represents the so-called "loop-gain function." In the lower diagram of Figure 8 the product $A_1A_2$ represents the so-called "loop-gain function." The closed-loop system function, M(s), is a complex function of the complex vari-

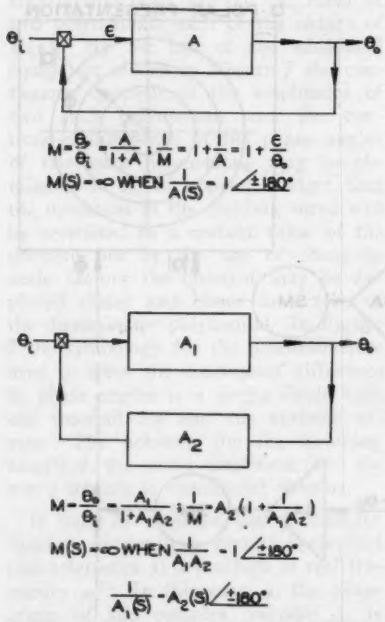

$\theta_i$
$\epsilon$
A
$\theta_o$
$M = \frac{\theta_o}{\theta_i} = \frac{A}{1+A}$ ; $\frac{1}{M} = 1 + \frac{1}{A} = 1 + \frac{\epsilon}{\theta_o}$
$M(S) = \infty$ WHEN $\frac{1}{A(S)} = 1 \angle \pm 180°$
$\theta_i$
$A_1$
$\theta_o$
$A_2$
$M = \frac{\theta_o}{\theta_i} = \frac{A_1}{1+A_1A_2}$ ; $\frac{1}{M} = A_2\left(1 + \frac{1}{A_1A_2}\right)$
$M(S) = \infty$ WHEN $\frac{1}{A_1A_2} = 1 \angle \pm 180°$
$\frac{1}{A_1(S)} = A_2(S) \angle \pm 180°$

FIGURE 8—Two Basic Types of Feedback Systems

able s expressing the ratio of the steady-state output to the steady-state input of the closed-loop feedback system. In the simple feedback system of Figure 8, the determinantal equation is given by

$$1 + A = 0 \qquad (5)$$

and, for the second system depicted in Figure 8, the determinantal equation is given by

$$1 + A_1A_2 = 0 \qquad (6)$$

Obviously the roots of each of these two equations are those values of s, the complex frequency variable, for which M(s) becomes infinite. In order for each system to be stable, the real parts of the roots of the determinantal equation must be negative, that is, the roots of the determinantal equation must lie in the left-half s-plane. Described differently, the *zeros* of the determinantal equation are the *poles* of the system function, M.

Subject to definite restrictions as to physical realizability, the loop-gain functions of such physical feedback systems are of the general form of

$$A(s) = \frac{K\,P_N(s)}{P_D(s)} \qquad (7)$$

where K is a positive real constant multiplier, establishing the so-called "loop-gain level" of the system, and where $P_N(s)$ and $P_D(s)$ are rational algebraic functions of the complex frequency variable s. Obviously $P_D(s)$ must have all its zeros lie in the left half s-plane if the loop-gain function itself corresponds to a stable system, with or without internal feedback.[12]

In general,[11] servomechanisms are that specific type of feedback system in which s to the first, second, or third power is factorable out of the denominator polynomial, viz.,

$$A(s) = \frac{K}{s^r}\frac{P_N(s)}{P_D(s)} \qquad (8)$$

In this case, A(s) is said to have "a first, second or third-order pole at the origin," depending upon whether r equals 1, 2, or 3. In general, $P_N(s)$ and $P_D(s)$ are characterized by the form

$$\frac{P_N(s)}{P_D(s)} = \frac{(1 + T_1s)(1 + T_3s)\,..}{(1 + T_2s)(1 + T_4s)\,..} \qquad (9)$$

where the T's are the so-called time constants of the system. They may be real or complex. If they are complex they occur in conjugate pairs. For example, $T_{11,12}$ would denote in this terminology the conjugate pair of time constants given by

$$T_{11,12} = x \pm jy \qquad (10)$$

It is evident that the T's are of the nature of reciprocal s's; hence,

$$\left.\begin{aligned} S_{11} &= -\frac{1}{T_{11}} = -\alpha_1 + j\beta_1 \\ S_{12} &= -\frac{1}{T_{12}} = -\alpha_1 - j\beta_1 \end{aligned}\right\} \qquad (11)$$

These two roots of a polynomial P(s) are evidently the conjugate complex pair whose $\sigma$-coordinate in the s-plane is $-\alpha_1$ and whose $j\omega$-coordinates in the

s-plane are respectively $+j\beta_1$ and $-j\beta_1$; or, more simply as depicted in Figure 9, wherein

$$S_{11,\,12} = -\sigma_1 \pm j\omega_1 \qquad (12)$$

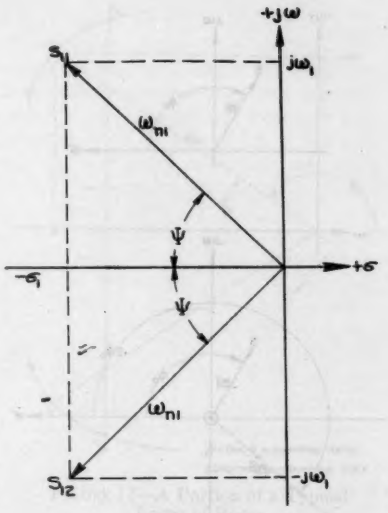
It is to be noted, with reference to Figure 9, that lines in the s-plane perpendicular to the $\sigma$ axis define contours of constant "damping constant." Furthermore, lines in the s-plane perpendicular to the $j\omega$-axis define contours of constant "undamped natural frequency." The radius vector drawn from the origin of the s-plane to any point in the complex s-plane represents in amplitude the "damped natural frequency." The cosine of the angle between the real axis of the s-plane and the radius vector representing the damped natural frequency is the so-called "damping ratio." The remainder of such useful relationships and definitions are as further defined in Figure 9.

It is useful to recollect here that if a system possess a pair of conjugate complex roots in its determinantal equation such as given by Equation (12) or the first line of Figure 9, it will exhibit in its time-behavior a time-component of the form

$$f(t) = e^{-\sigma_1 t}\ (\cos \omega_1 t + j \sin \omega_1 t) \qquad (13)$$

This corresponds to an exponentially damped sinusoidal oscillation of angular periodicity in time of $\omega_1$, with a phase angle. As the locus of the roots $s_{11}$, $s_{12}$ moves about in the complex s-plane the corresponding time behavior will vary from that of a pure exponential function of time (corresponding to $\omega_1 = 0$) to a pure sinusoidal oscillation in time (corresponding to $\sigma_1 = 0$). If, of course, the radius vector $\omega_{n1}$ extends into the first or fourth quadrants of the complex s-plane the system corresponding thereto will exhibit the unstable characteristic of an exponentially increasing time function.

In Figure 10 is depicted the variable s and its amplitude $|s|$ and its phase angle, say, $\varphi_0$. In the lower of the two diagrams of Figure 10 there is graphi-




$S_{11}, S_{12} = -\sigma_1 \pm j\omega_1 = -\xi\omega_{n1} \pm j\omega_{n1}\sqrt{1-\xi_1^2}$

$\sigma$ = DAMPING CONSTANT

$\omega$ = UNDAMPED NATURAL FREQUENCY

$\xi$ = DAMPING RATIO

$\omega_n$ = DAMPED NATURAL FREQUENCY

$\xi = \cos\Psi = \frac{\sigma}{\omega_n}$ ; $\sqrt{1-\xi^2} = \sin\Psi = \frac{\omega}{\omega_n}$

FIGURE 9—Definitions and Properties of the Complex Frequency Variable

cally symbolized the interrelationship between the complex variable s and its square $s^2$. To graphically depict $s^2$ the length of the radius vector $|s|$ is multiplied by itself and is drawn from the origin of the s-plane with an angle $2\varphi_0$ with respect to the positive axis of reals; similarly for $s^3$, etc.

With the foregoing nomenclature, definitions, and interpretations in mind, it is now possible to proceed to a consideration of "a locus-of-roots computer" of great use in the design of servomechanisms, feedback amplifiers,

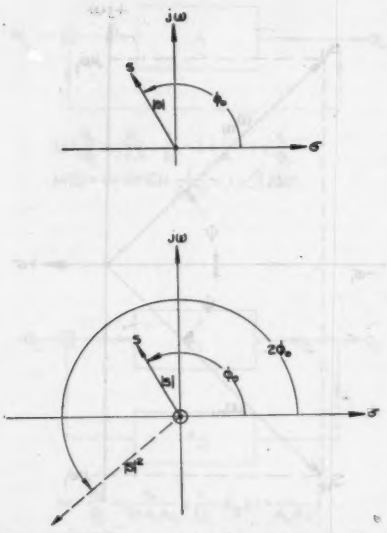



FIGURE 10—Representation of the Complex Frequency Variable, and Its Powers, on the Complex Frequency Plane

networks, and analogous dynamical systems.

From the foregoing it is clear that the locations of the zeros of the determinantal equation corresponding to a physical system, once the functional form of the loop-gain function is described, become a function of the value of K, the loop-gain level. This coincides with physical knowledge and mathematical theory. For example, Figure 11 depicts qualitatively the A-function loci of a very elementary form of servomechanism whose loop-gain function is expressed as

$$A = \frac{K}{S(1 + T_{11}s)(1 + T_{12}s)} \qquad (14)$$

In this case, a servomechanism is characterized by a single order pole at the origin and a pair of conjugate complex time constants $T_{11}$ and $T_{12}$, of the form given by Equation (11). Application of the servomechanism practical stability criterion enunciated by the author and a former colleague,[15] it is evident that only with a loop-gain level of $K < 2\alpha_1$ is this system stable, for the reason that, with values of $K > 2\alpha_1$ the Nyquist point, $-1 + j0$, is seen to the right when standing on the A-locus on the A-plane facing in the direction of increasing real frequency. In other words, a loop-gain value of $K = 2\alpha_1$ is that value of K which makes the real parts of the roots of this system's determinantal equation zero.

It is of interest and use to know the manner in which the zeros of the determinantal equations of such systems move about in the s-plane as K, the loop-gain level, is varied from zero to infinity. Among other things, knowledge of the locus of roots defines the values of gain level required for establishing the stability of systems possessing only conditional stability. It might be anticipated that the trajectory or locus of such roots in the s-plane would take on paths such as those depicted in Figure 12, as the loop-gain level, K, is

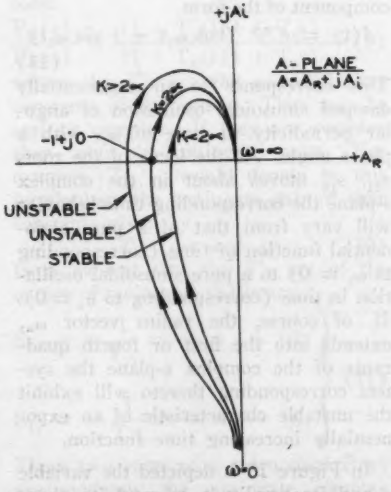



FIGURE 11—A Typical Application of the Nyquist Stability Criterion to Feedback Systems

varied from zero to infinity. From Figures 9 and 12 it is also evident that the locus of roots will intersect successive vertical lines perpendicular to the axis of reals in the s-plane corresponding to successive values of damping constant, $\sigma$. Finally, such a locus of roots will intersect the various radial lines on the s-plane originating from the origin of the s-plane, each corresponding to a different damping ratio, $\xi$. It is very often desirable to design the system or adjust the gain level of a system to a specific level of K corresponding to a specific damping constant, $\sigma$, or damping ratio, $\xi$. In other words, if it is desired that a certain system yet to be designed exhibit a certain value of damping constant or of damping ratio, it is of great value in system design to be able to know that such a damping constant or damping ratio is actually available by appropriate setting of K, the loop-gain level. It is also desired in many cases to know what change in the location of the critical frequencies (the complex zeros) of the system will make it possible to establish a desired value of K. All of these and many other purposes

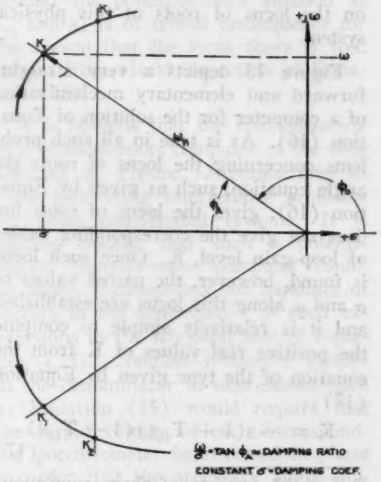



FIGURE 12—A Portion of a Typical Locus of Roots

underlie the value of the locus-of-roots interpretation of the analysis and design problem.[4]

Returning now to Equation (14), and with reference to Figure 8, it is obvious that

$$\frac{s(1 + T_{11}s)(1 + T_{12}s)}{K} = -1 = 1 \angle \pm 180° \pm n360° \qquad (15)$$

where n is integral, becomes the defining equation for the locus of roots of the servomechanism or feedback system whose loop-gain function is defined in Equation (14). Obviously the three complex factors in the numerator of the left-hand side of Equation (15) each contribute a phase angle. In the nomenclature of Figure 13, the phase angle equality satisfied along the locus of roots is given by

$$\Phi_0 + \Phi_{11} + \Phi_{12} = \pm 180° \pm n360° \qquad (16)$$

In other words, any time the three phase angles of the vectors drawn from the origin, from $s_{11}$ and from $s_{12}$, to a typical point in the s-plane, add up to 180°, that point (or value of s) lies

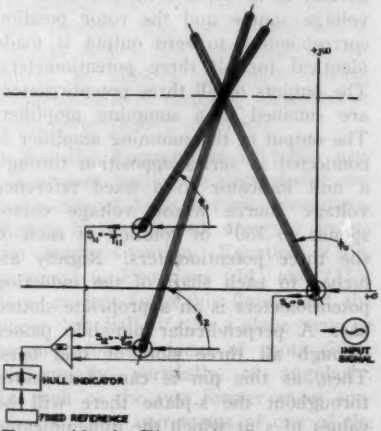



FIGURE 13—An Elementary Locus-of-Roots Computer

on the locus of roots of this physical system.

Figure 13 depicts a very straightforward and elementary mechanization of a computer for the solution of Equation (16). As is true in all such problems concerning the locus of roots the angle equation, such as given by Equation (16), gives the locus of roots but does not give the corresponding values of loop-gain level, K. Once such locus is found, however, the paired values of $\sigma$ and $\omega$ along this locus are established and it is relatively simple to compute the positive real values of K from the equation of the type given by Equation (17):

$$K = -s(1 + T_{11}s)(1 + T_{12}s) \qquad (17)$$

Figure 13 consists of three continuous one-speed potentiometers[7, 8] whose angle of rotation of 360° produces a voltage proportional thereto and in which 0° represents zero output voltage. One such potentiometer is fixed at a point corresponding to the origin of coordinates of the s-plane. The other two potentiometers are located to an appropriate scale at the points representing $s_{11}$, $s_{12}$. Each potentiometer is excited at its input from the same a.c. voltage source and the rotor position corresponding to zero output is made identical for all three potentiometers. The outputs of all three potentiometers are summed in a summing amplifier. The output of the summing amplifier is connected in series opposition through a null indicator to a fixed reference voltage source whose voltage corresponds to 180° of rotation of each of the three potentiometers. Rigidly attached to each shaft of the induction potentiometers is an appropriate slotted bar. A perpendicular pin-slide passes through all three slots of said bars. Then, as this pin is caused to move throughout the s-plane there will be values of s at which the null indicator will read zero. Such values of s satisfy Equation (16). Figure 14 illustrates the locus of roots which the elementary computer of Figure 13 may draw, corresponding to Equations (15) and (16), in which the coordinates of $s_{11}$, $s_{12}$ are as given.

In further utilizing this simple example, it is evident that large values of s will correspond to all three angles $\varphi_0$, $\varphi_{11}$, $\varphi_{12}$ approaching equality. From Equation (15) this gives as the asymptotic behavior of the locus of roots for increasing large s, the two lines, $\pm 60°$. In the limit, the corresponding gain level K is also infinity. Further examination of Equation (15) shows that $s = 0$, $s = -1/T_{11}$, $s = -1/T_{12}$, each correspond to a point on the locus of roots for which K is zero. In other words, as the loop-gain level, K, increases continuously through positive real values from zero to infinity the locus of roots is qualitatively that depicted in Figure 14.

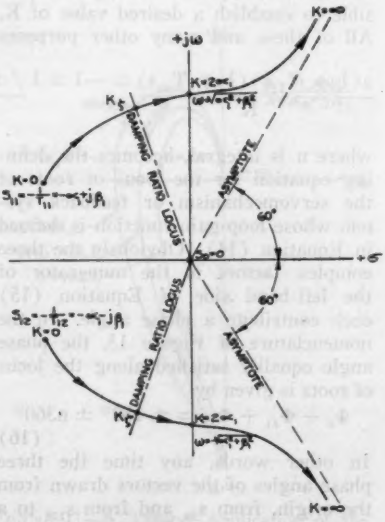



FIGURE 14—A Complete Locus-of-Roots for an Elementary Servomechanism

Many interesting conclusions may be drawn from Figure 14. First, the feedback system corresponding thereto is a conditionally stable system, that is, as the loop-gain level K is increased there is some value of K for which the system will become unstable; this occurs when the locus of roots crosses the imaginary axis in the s-plane in going from the left half-plane to the right half-plane. This is exactly what was deduced from the customary Nyquist stability criterion considerations of Figure 11. Second, with this system, damping ratios whose loci lie between the negative real axis and the radius vector drawn from the origin to $s_{11}$ and $s_{12}$ are not attainable, regardless of the value of the loop-gain level value, K. Third, the loop-gain level if set to a value, $K_\xi$, will cause this system to exhibit a corresponding damping ratio, $\xi$, where $\xi$ is defined as in Figure 9. Fourth, a loop-gain level of $K = 2\alpha_1$ will make the corresponding feedback system a stable oscillator generating a frequency of $\omega = \sqrt{\alpha_1^2 + \beta_1^2}$. Fifth, it is clearly evident that the locus of roots exhibits the properties of complete symmetry about the real axis of the s-plane. Sixth, the right half-plane is not of primary interest since it corresponds to a region of wholly unstable behavior. Seventh, it is therefore concluded that a locus-of-roots computer need plot only that portion of the locus of roots contained in the upper left-half complex s-plane, the second quadrant.

Therefore, with respect to the very elementary computer depicted in Figure 13 it is only necessary that successive fixed increments in the $\omega$-coordinate of the pin-slide be made, the real coordinate $\sigma$ being traced in each case from some convenient negative value to zero. In this manner of rectangular scanning of the second quadrant the important portion of the corresponding locus of roots may be marked out by a printer actuated each time the null indicator reads zero. Mechanical interference around the potentiometers situated at $s_{11}$ and $s_0$ is of trivial consequence for the reason that the locus there is well known from visual inspection of Equation (15).

It is obvious that the mechanization of a locus-of-roots computer of the type depicted in Figure 13 would lead to some interesting interference problems for more complicated systems. It is equally evident that such a potentiometer locus-of-roots computer could, on paper, accommodate the handling of factors in the denominator of such expressions as the left-hand side of Equation (15). Complex frequency factors in the denominator in expressions such as Equation (15) would require that the output voltage of each corresponding potentiometer be reversed in phase in order that the necessary angle subtraction may be accomplished electrically in fulfilling an equation corresponding to Equation (16). It should not be mistakenly assumed that typical loci are generally of the "single branch variety" depicted in Figure 14. Systems of typical complexity consisting of a number of pairs of conjugate complex zeros and poles and a number of zeros and poles on the negative real axis give rise to a number of branches comprising the total locus-of-roots of such systems. One such branch will in general control the gain level, K, required to achieve a desired system damping-ratio or damping coefficient or some other desired attribute.

For the presentation of some new conceptions leading to more useful embodiments of locus-of-roots computers, Figure 15 is employed. It again depicts the angle situation, Equation (16), pertinent to Equations (14) and (15). It is evident from this figure that the upper left half of the s-plane may be scanned for the locus of roots either horizontally, vertically, or angularly. In each of the two former cases successive, fixed increments of one of the two rectangular coordinates of s are

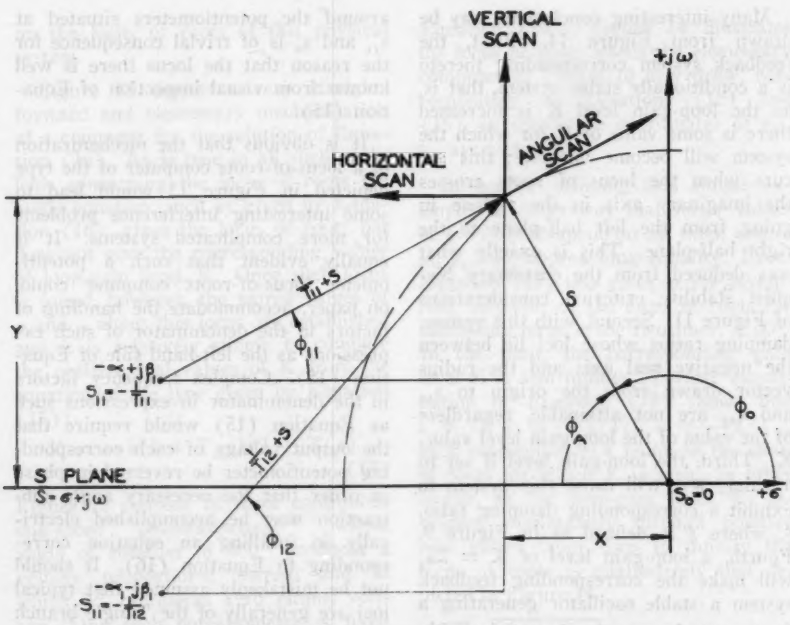



FIGURE 15—Vertical, Horizontal, and Angular Scan of Complex Frequency Plane

assumed, the other coordinate of s each time varying through a convenient range of values from zero to some negative maximum and return. In the third method of scan, angular scan, as $|s|$ gradually increases from zero to some maximum value, the angle $\varphi_A$ is relatively rapidly caused to rotate through the range from zero to 90°, and return, continuously. The variation in $|s|$ may be effected either on a step-wise basis such as shown in the upper diagram in Figure 16 or on a continuous, increasing spiral basis, as depicted in the lower diagram on Figure 16.

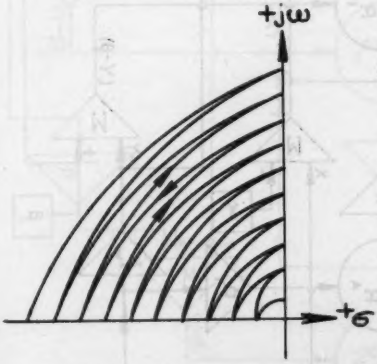
In terms of the two variables X and Y appropriate to the horizontal and vertical scans depicted in Figure 15, Figure 17 illustrates the topological situation corresponding to the zero distribution of Figure 15 and Equation (15). Here, in terms of right triangles whose hypotenuses are, respectively, co-linear in space with one side of at least one other right triangle, the entire locus-of-roots computer problem is restated in a highly useful form. With $\alpha$ and $\beta$ fixed, X and Y are varied in some convenient fashion (for example, in horizontal or vertical scan). Values of X and Y, as defined in Figure 15, which correspond to points on the locus of roots of the system specified by Equations (14), (15), and (16), will be indicated by satisfaction of the equality

$$\phi_{11} + \phi_{12} = \phi_A \qquad (18)$$

Thereby the entire locus-of-roots in the upper left-half of the s-plane may be determined.

It is of considerable significance that changes in $\alpha$ and $\beta$ may easily be introduced in order to determine how the coordinates X, Y, of any specific point

STEP-WISE SCAN OF S.




SPIRAL SCAN OF S.

FIGURE 16—Step-Wise and Spiral Scan of Second Quadrant of Complex Frequency Plane

on the locus of roots are perturbed by variation in $\alpha$ and $\beta$. Such perturbations in $\alpha$ and $\beta$ resulting in corresponding perturbations in X, Y on the locus of roots are of very great importance because they correspond to "variations in physical time constants"

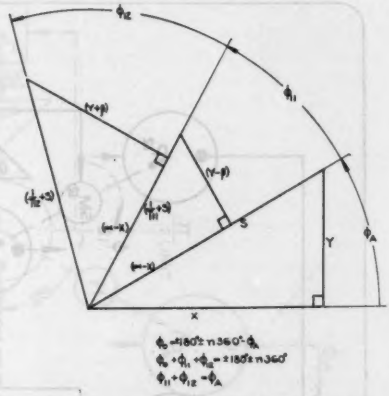



FIGURE 17—Topological Situation Corresponding to a Simple Servo-mechanism Function

of the system. These variations in time constants, in turn, may be associated directly with changed physical parameter values, such as resistors and capacitors. It is possible to establish manufacturing and environmental tolerances on such element values in terms of allowable deviations in the locus of roots and, hence, of the performance of the system in which they are incorporated.

In Figure 18 appears a complete, practical computer mechanization for the determination of the locus of roots of the simple system whose loop-gain function is described by Equation (14). The technique of its extension to cover more complex loop-gain functions, involving more factors in the denominator and factors in the numerator of the ratio of polynomials describing the loop-gain function, are straightforward and are limited in extent only by the accuracy and signal-to-noise ratios of the components of the system.

The computer depicted in Figure 18 employs electromagnetic a.c. induction resolvers and potentiometers (denoted by R and P respectively), servo motors, gear trains (not specifically shown),

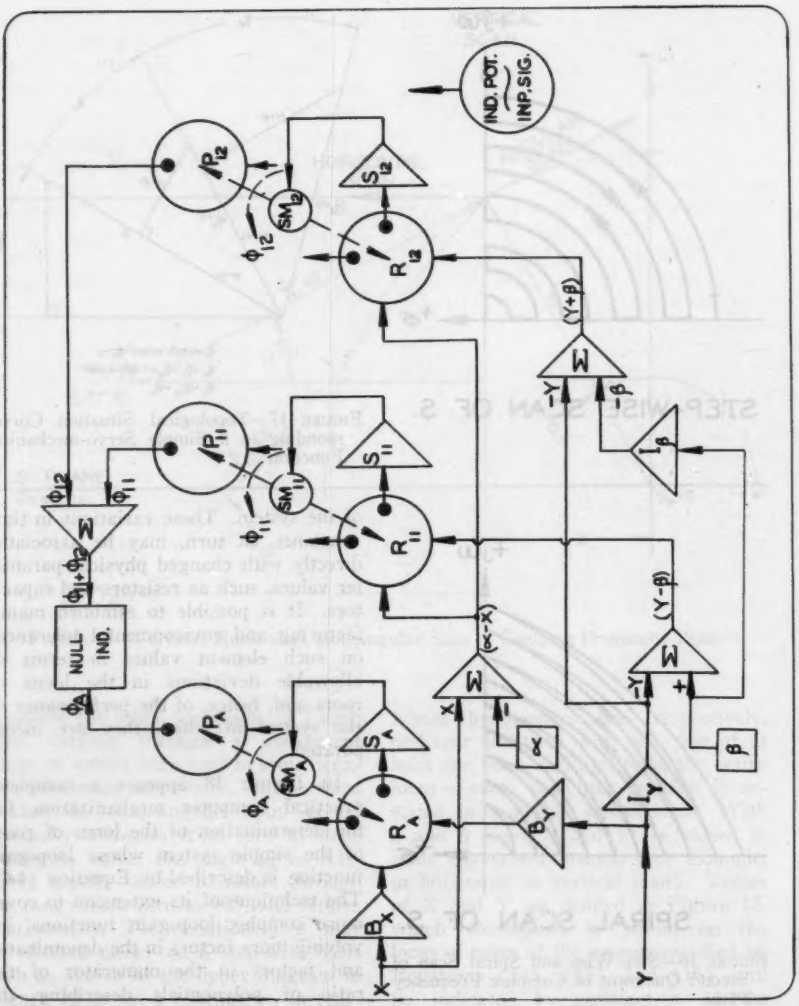



FIGURE 18—Complete Mechanization of a Locus-of-Roots Computer Utilizing Horizontal and Vertical Scanning

FIGURE 19—Complete Mechanization of a Locus-of-Roots Computer Utilizing Step-Wise or Spiral Scan

servo amplifiers (denoted by the symbol S), summing amplifiers (denoted by the symbol Σ), booster amplifiers (denoted by the symbol B), inverting amplifiers (denoted by the symbol I), and, finally, critical frequency settings, typically represented by the boxes labelled $\alpha$ and $\beta$. These latter may be obtained from voltage sources through potentiometers of appropriate scale factor. By their adjustment $\alpha$ and $\beta$ may be moved to new convenient locations to determine the corresponding modifications of the locus of roots obtained.

In operation of the computer depicted in Figure 18, X is assigned some con-

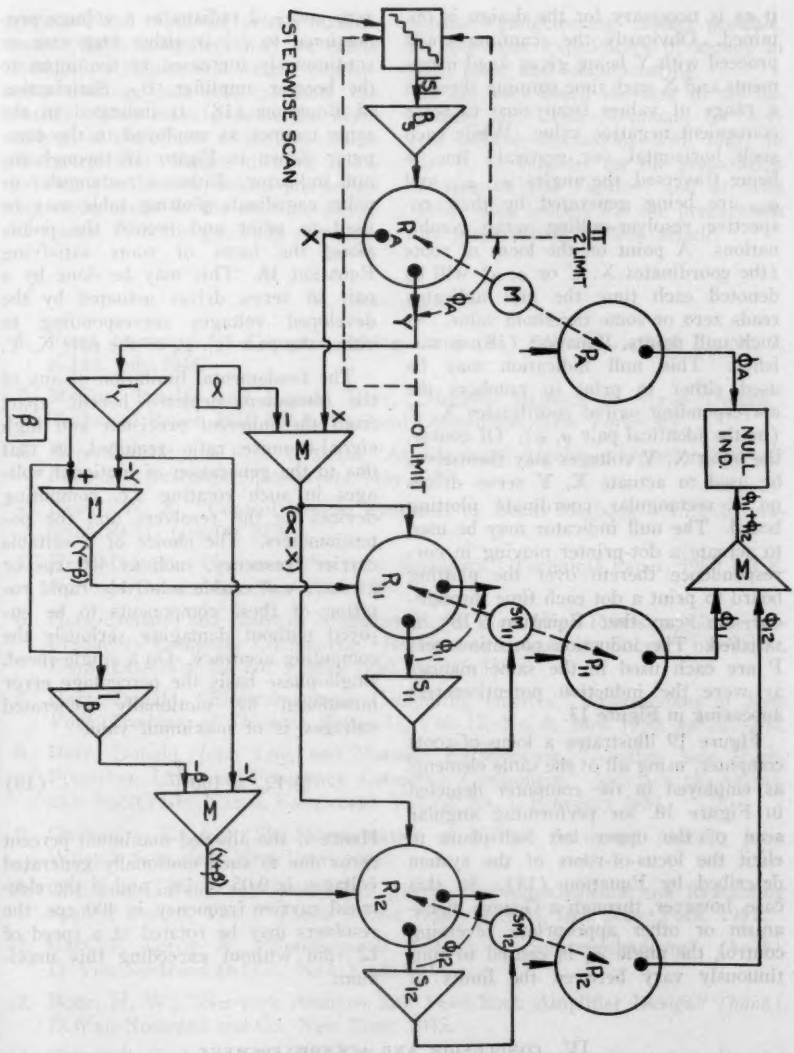



FIGURE 19—Complete Mechanization of a Locus-of-Roots Computer Utilizing Step-Wise or Spiral Scan

FIGURE 18—Complete Mechanization of a Locus-of-Roots Computer Utilizing Horizontal and Vertical Scanning

venient fixed value. Y is then varied continuously from zero to a convenient large positive value. X is then increased incrementally to some new fixed value and Y is caused to return to zero. X is incrementally increased the third time to a third fixed value and Y again is varied from zero to some convenient positive value. This scanning of the upper left half s-plane is continued until the entire locus-of-roots in that quadrant is obtained or until such part of

it as is necessary for the design is obtained. Obviously the scanning could proceed with Y being given fixed increments and X each time running through a range of values from zero to some convenient negative value. While each such horizontal (or vertical) line is being traversed, the angles, $\varphi_A$, $\varphi_{11}$, and $\varphi_{12}$ are being generated by their respective resolver-nulling servo combinations. A point on the locus of roots (the coordinates X, Y or $\sigma$, $\omega$) will be denoted each time the null indicator reads zero or some threshold value. At such null points, Equation (18) is satisfied. This null indication may be used either to print in numbers the corresponding paired coordinates X, Y (or the identical pair $\sigma$, $\omega$). Of course, the input X, Y voltages may themselves be used to actuate X, Y servo drives on a rectangular coordinate plotting board. The null indicator may be used to actuate a dot-printer moving in correspondence thereto over the plotting board to print a dot each time throughout the scan that Equation (18) is satisfied. The induction potentiometers P are each used in the same manner as were the induction potentiometers appearing in Figure 13.

Figure 19 illustrates a locus-of-roots computer, using all of the same elements as employed in the computer depicted in Figure 18, for performing angular scan of the upper left half-plane to elicit the locus-of-roots of the system described by Equation (14). In this case, however, through a Geneva mechanism or other appropriate reversing control, the angle $\varphi_A$ is caused to continuously vary between the limits of zero and $\pi/2$ radians as a voltage proportional to $|s|$ is either step-wise or continuously increased at the input to the booster amplifier, $B_g$. Satisfaction of Equation (18) is indicated in the same manner as employed in the computer shown in Figure 18 through the null indicator. Either a rectangular or polar coordinate plotting table may be used to print and record the points along the locus of roots satisfying Equation 18. This may be done by a pair of servo drives actuated by the developed voltages corresponding to either the pair $|s|$, $\varphi_A$ or the pair X, Y.

The fundamental limitation of any of the computers depicted herein, apart from the inherent precision and high signal-to-noise ratio required, is that due to the generation of motional voltages in such rotating a.c. computing devices as the resolvers and the potentiometers. The choice of a suitable carrier frequency, such as 400 cps or greater, will enable relatively rapid rotation of these components to be enjoyed without damaging seriously the computing accuracy. On a single-speed, single-phase basis the percentage error introduced by motionally generated voltages is of maximum value

$$\% E_m = 100 \frac{f_m}{f_e} \qquad (19)$$

Hence if the allowed maximum percent error due to such motionally generated voltages is 0.05 of 1%, and if the electrical carrier frequency is 400 cps, the resolvers may be rotated at a speed of 12 rpm without exceeding this maximum.

## IV. CONCLUSION AND ACKNOWLEDGMENT

Each of the two computers described herein may be built with a sufficient degree of complexity to solve most everyday design and analysis problems which can be handled by polynomial plotters and locus of roots solvers. These two computers may be individually fabricated at a cost not beyond the realm of possibility for the medium- and small-sized company or institution. They may be built from readily available components having long life, high

precision, and relatively simple maintenance. Such computers may be easily fitted into a volume and weight requirement making desk-side, portable use feasible. They make possible the rapid analysis of the effects of various design parameters and changes therein, in order that the less expensive pre-design may come closer to the ultimate physical system than the generally more expensive "gadgeteering" makes possible, for the same expenditure of money in time, labor and manufacturing.

I am very much indebted to my assistant, Mr. Leon Steinman, for several helpful discussions with him; to Mr. B. R. Wheeler for the preparation of some of the Figures; and to Miss Helen Jane Gilbert for the preparation and proofreading of this article.

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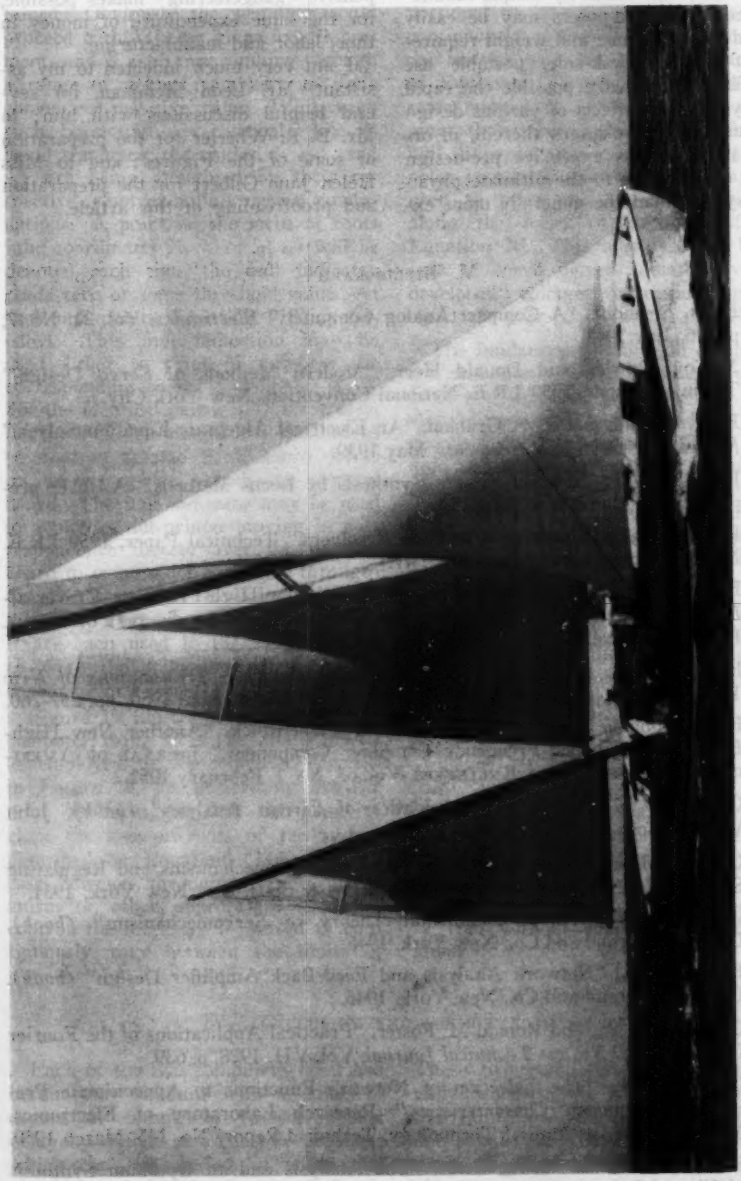


The largest one-piece laminated plastic hull yet produced—the 42' *Orion* built by Anchorage Plastics, Warren, R. I.

# PLASTIC BOAT PROGRAMS

COMMANDER ARTHUR C. BUSHEY, JR.

THE AUTHOR

COMMANDER BUSHEY is stationed in the Bureau of Ships, Contract Design (Hull). He was commissioned 28 February 1930 as a Lt. (J.G.)—Construction Corps, U. S. Naval Reserve. On 7 October, 1940 he was called to active duty and assigned to the Design Section of the Norfolk Navy Yard. To aid the training of personnel in that rapidly expanding organization, he organized the University of Virginia Norfolk Extension for Naval Architecture, teaching in the evenings for two years. He was next assigned to the Pacific. He holds the Bronze Star Medal. Recently the King of England appointed him an O.B.E. in recognition of his services as officer in charge of shipbuilding and ship repairs in New Zealand and commanding officer of the U. S. forces in Auckland.

It is assumed that the reader has a speaking acquaintance with glass reinforced laminated plastics and has probably read my articles appearing in the February and November 1948 issues of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS as well as the comments on the first article appearing in the May 1949 issue.

Mass production of plastic boats is now needed to settle many of the issues which presently face plastic boat designers. It is true that in private industry plastic boats are being made in larger quantities than they were previously. These boats are reasonable in cost and are generally in the 9′ to 18′ length class; although 22-foot cruisers are now being produced commercially by one firm, and another recently successfully completed a 42-foot sailing ketch, which is the largest laminated plastic hull yet produced. Many of the plastic boats are made with simple styling, but probably the greater number are made to the runabout design. The plastic material lends itself well to this attractive, yet complicated design, because the hull up to a raking sheer line is made in one set of molds, and the decking with the upper part of the hull is made in another set; the two parts are joined together with mechanical fastenings covered by a metal strip or an attractive fender, which gives the completed job an elegant touch. These boats have as their selling points—durability, a permanent coloring which does not fade, water-tightness, functional beauty with strength, and rot and worm proofness.

Perhaps even more important, particularly in time of emergency, is the ready availability of the materials used to construct them; specifically, polyester resins, which are compounded mainly from by-products of coal and petroleum; and woven or matted glass filaments. Production facilities for both these commodities are now being expanded to provide for greatly increased military requirements. A further important con-

sideration is the fact that highly-skilled shipbuilding labor is not necessary for the construction of plastic boats; and the total number of man hours is about one-fourth that required for the production of similar boats of conventional materials.

Because of the low specific gravity and the good physical properties of the laminated plastic material, it is easy to make a hull which is lighter than comparable wood or aluminum hulls yet with sufficient thickness readily to withstand local impact loads caused by collisions with other boats, piers and piling. The latter feature, of providing sufficient thickness to withstand impact loads, has made the plastic boat a better seller than the thin metal boats, which are usually made of aluminum. The plastic craft are made by the several methods described in previous articles. The materials used provide more than enough strength for boats of these sizes.

At best, however, because of the competition in this field, the number of plastic boats built by any manufacturer to date has been rather limited.

The small craft just referred to are basically simple in design. Designs vary widely with the several manufacturers, but in general the hulls are made to a single thickness throughout, with longitudinal reinforcement provided by the shaped keels, or aluminum or plastic pre-forms inserted in the laminates and, further, in the shape of the gunwale, or at the deck juncture which is provided in runabouts. Transverse stiffening is given by the thwarts and their plastic or mechanical connection to the hull proper. As indicated previously, these boats have strength to spare and compete with both wood and aluminum boats of the same size excellently because of less weight. Problems of design in these boats are minor and with weight to spare, adequate additional local strength has been provided by the manufacturer wherever experience dictates its necessity.

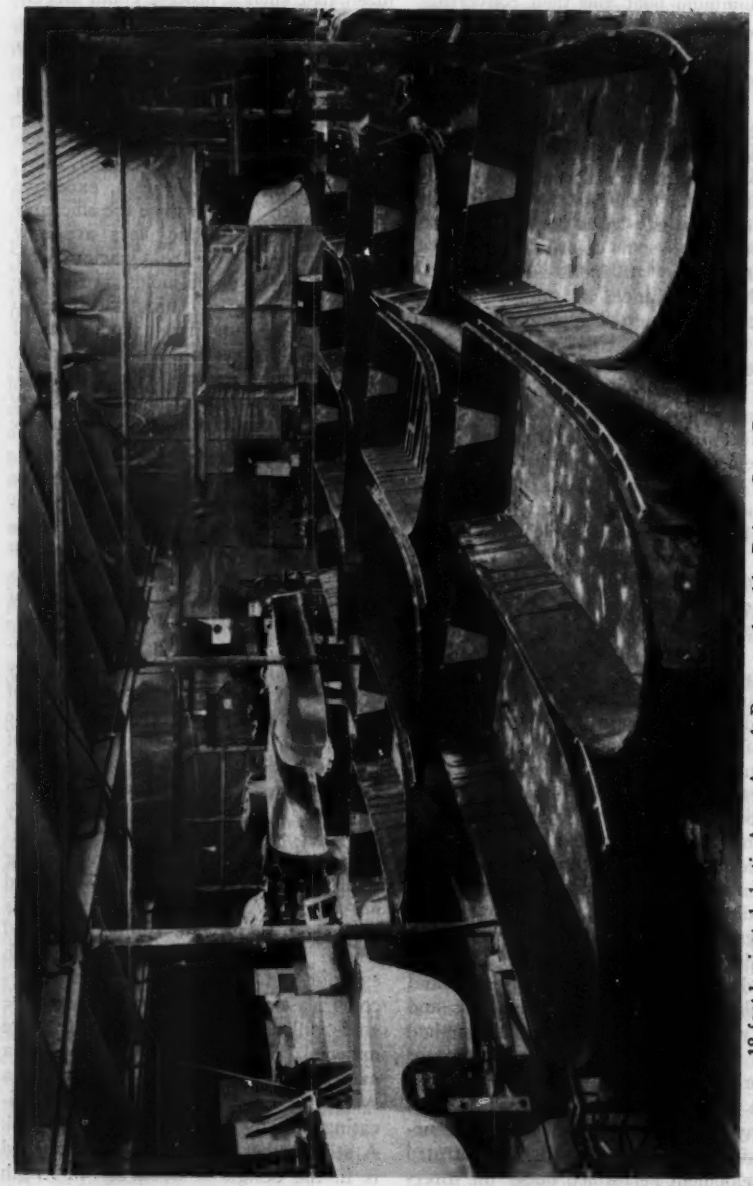
The big problem facing the designer and producer is when boats of greater length and particularly those with built-in propulsion machinery of high power are considered. Longitudinal framing to take the loads imposed by the propulsion machinery and some transverse framing are required. Commercial pleasure cruisers up to 24′ in length have been built, incorporating the strength in longitudinal members and in the transverse bulkheads. Such cabin cruisers are elegant in appointment but yet quite simple in basic design. It must be remembered that as boats increase in length, at a certain length, metal boats can be built with equivalent strength from all aspects to that of wood. This length, of course, varies with the design or rather, with the service for which the boat is intended. For boats in the tug class, this length is in the neighborhood of 55′. With plastic boats the weight-wise superiority over wood increases with length. However, as the length of plastic boats increases from 50 to 100 feet, their superiority weight-wise over aluminum and steel has a narrow margin. This means that the simple design (and sometimes lack of design) characteristic in boats under 20′ in length must give way to a more involved and detailed design.

The method of design of larger plastic boats up to the present has been quite simple. In many instances it has been accomplished by providing the boat with a skin weighing about 10% less than the wood or aluminum skin, and with scantlings of the same section modulous as that found in the competitive prototype wood or aluminum. A savings of more than 10% is usually obtained in the scantlings. Thus, in the larger plastic boats, a savings of over 10% in weight has been achieved. The resultant construction from this design method has proven itself in service. Until more basic design data are obtained, this method of designing a wooden

or aluminum boat and then converting it to plastic design must remain.

A mass production program would entail the development of positive controls to avoid to a large degree the weaknesses now existing in the several methods of building plastic boats. Most of the problems are attendant upon the molds in which the boats are made. If the manufacturer has a mass production program, he can afford to make a greater outlay of funds for improved molds. Assurance of uniformity of structure through complete impregnation of the resin could also be solved by techniques which could be developed in a mass production program. In a mass production program of boats under 20 feet in length where strength requirement is limited, it is considered that any of the present well known methods of fabrication may be able to develop such quality controls in production that a boat of satisfactory quality could be produced. The methods involved are (1) the wet lay-up of laminates in a female mold and the application of pressure to these laminates by a vacuum or pressure blanket and (2) the "Marco Method" in which matching molds are used with dry lay-up of glass reinforcement followed by injection of resin after closure of the molds. For boats of 20-foot length and greater, it is considered that the matching mold method is the only sound and economical process. This method is based on a patent owned by Marco Chemicals Inc., Linden, New Jersey, which covers impregnation of the reinforcing materials by introduction of the resin into the mold cavity through use of a differential in the pressure between the molds and the resin to be introduced. This method was developed during the early part of World War II but its effective application to large molded laminates presented many unique problems. These were successfully solved through concentrated development performed under the direction of the Bureau of Ships, who recognized that such a process could largely overcome all the major disadvantages encountered in the earlier wet lay-up procedure such as resin drainage, entrapped air pockets, localized resin pools, varying hull thickness, and non-uniform resign impregnation (which results in non-uniform strength), slow, messy handling of the resin, excessive finishing, etc. To illustrate the efficiency of this process, arctic sleds are now being produced for the Quartermaster Corps, using multiple molds, at the rate of one sled every 2½ minutes. Since no orders calling for mass production of boats have as yet been issued, similar speeds have not yet been attempted. It is felt, however, that comparatively rapid mass production of boats is now possible by this process.

The Marco Method as used for the production of boats involves two matching molds, the distance between the molds being the thickness of the hull of the boat. Moreover, this process permits the successful incorporation of the hull framing directly into the casting of the hull. Such a procedure involves usually a male mold with many recesses, representing the framing of the boat. This makes the molds more costly, but eliminates the necessity of installing reinforcing members as a separate step. A variation has been provided in the construction of Navy 26-foot boats by making the hull thickness the same throughout and adding reinforcement by means of laminated pre-forms. Another variation of this method is to provide simple male and female molds to provide for smooth exterior and interior skins and a honeycomb plastic structure between, with the voids filled with a low density core material. Such a procedure requires a mass production program to evolve a system of quickly and efficiently fabricating suitable blocks of core material. A still further variation of this method is in the design of boats 50′ in length and greater, with their complicated



18-foot laminated plastic Army Assault Boats produced by Palmer Scott Company using the Marco Method

structure, decking, housing and many components, where the hull proper is made to a single thickness in two matching molds, the decking, bulkheads and houses in similar sets of matching molds, and the frames likewise in molds. These components are then joined together by epoxy or polyester resins and mechanical fastenings.

Laboratory tests have indicated that the laminates with optimum physical characteristics are obtained when the glass content is 55% and the resin content 45%. However, in actual building practice, the best results are obtained when the glass content is about 35-40% and the resin content 60-65%. It has been found that wood inserted between laminates is unsuitable because of the dimensional instability of wood and that aluminum is not appreciably better because of poor bonding to the plastic. Laminated plastic pre-forms are preferable as inserts for fastening, stiffening or framing purposes. The use of tailor-made resins has become more widespread. The former high temperature reached in thick laminates during the exothermic reaction have been greatly reduced through the use of a new room temperature-curing resin, where the temperature during polymerization in thick blocks is less than 140° F. This has been a great help in many directions, particularly in permitting the use of certain low density core materials which otherwise would deteriorate under high temperatures. Wood molds, even if plastic covered, are now being discarded except for limited production runs. This again is due to the dimensional instability of wood. Male and female molds alike can be made of steel but probably the best molds of the immediate future will be those of laminated plastic reinforced with glass for the matching mold process, with suitable reinforcement added later for handling purposes. Molds have been, and probably will continue to be, sectionalized for large boats, and the number of injection troughs or pipes has increased from the simple trough around the base of the matching molds to as high as eight. Likewise, the number of suction lines for resin take-up has increased actually in the production of larger boats from one to three and in one instance, six in number.

In spite of the many advantages of laminated glass plastic construction, providing a monolithic structure of beauty, strength and durability, it is of necessity tied to the building of boats in quantity, because the savings which accrue through savings in man-hours in construction are offset by (1) the greater cost of materials per pound and (2) the cost of the molds. The first item is continuing, the same weight of materials enter each boat regardless of the quantity built, but the second can be amortized in a large building program. In a similar manner, production processes can be amortized in a large construction program.

Plastic runabouts are now being built commercially in simple matching molds. One, 14′ long, 56″ beam, with built-in flotation material and provision for an outboard motor up to 25 hp., weighs only 220 pounds; 100 pounds less than the previous design which was built with but one mold. The Navy 26′ boats, previously mentioned, are being built in simple matching molds of plastic. The Navy 36′ design has been produced in matching molds of steel. These boats have laminated glass plastic double hulls, 8″ to 24″ apart depending on the shape of the hull, the two hulls connected by laminated glass plastic webs, providing thereby a honeycombed structure, which contains a low density flotation material. To illustrate the thoughtful engineering of the design an outline description of the molds and process is given.

A. Male Mold (Inverted)

1. Construction of.

(a) 4 sections. (b) Seals at joints. (c) ⅛″ steel skin with

$3\frac{1}{2}$" x $3\frac{1}{2}$" x $\frac{3}{8}$" steel bounding angles and $\frac{5}{16}$" flanged steel plates for framing, generally on 20" centers.

2. Use during process.
   (a) Used as one unit, although provision made for removal of each section.
   (b) Provision made for hydraulic pressure to lift finished hull from mold.

B. Female Mold.

1. Construction of.
   (a) 13 sections. (b) Seals at joints. (c) $\frac{1}{16}$" or less sheet steel reinforced with strongback longitudinally.
2. Use during process.
   (a) Each unit set in place and removed separately.

C. Preparation.

1. Molds thoroughly cleaned with acetone.
2. Molds polished with two coats heavy duty floor wax.
3. Liquid release or parting agent sprayed over the wax.

D. Lay-up (on inverted male mold)

1. Overlay of pigmented resin (MR-28C) sprayed on male mold.
2. One (1) layer of No. 1000 glass cloth.
3. Three (3) layers of polyester bonded glass mat—$1\frac{1}{2}$ ounces per square foot.
4. One (1) layer of No. 1000 glass cloth.
5. Metal inserts, such as life jacket recess boxes.
6. Low density core or flotation material blocks.
   (a) With presently available flotation material, great care must be exercised in wrapping the blocks and then coating them so that the resin under heat of the exothermic reaction will not penetrate the blocks (Flotation materials under development will probably permit simplification of this part of the process).
7. Webs.
   (a) Webs are formed between the blocks through use of two (2) layers of glass mat, the laminates extending around the edges of the blocks to form T-joints with the inner and outer hulls or skins.
8. One (1) layer of No. 1000 glass cloth, first of outer skin.
9. Three (3) layers of polyester bonded glass mat—$1\frac{1}{2}$ ounces per square foot.
10. One (1) layer of No. 1000 glass cloth.
11. Partial layer of No. 1000 glass cloth in scuffing areas.
12. Overlay of pigmented resin (MR-28C) sprayed on female mold.

E. Covering of lay-up with female mold.

F. Injection of resin.

1. Vacuum method.
2. Injection modified MR-28V via channels progressively, to inside and outside of skins, from bottom upwards.
3. Control of injection channels by separate vacuum control system.
4. Control of exothermic temperature by new room temperature curing resin.

G. Removal of female mold.

1. By sections.

H. Removal of boat from mold after cure.

1. By hydraulic pressure from under side when necessary. (Tendency to shrink in 36' length during heat of exotherm is $\frac{3}{8}$" and would be $\frac{1}{4}$" 24 hours later.)

I. Finished Hull.

1. Total weight—6611 pounds.
   (a) 3200 pounds of polyester resin.
   (b) 2271 pounds of laminated glass.
   (c) 1140 pounds of inserts, fuel tanks, etc.

From the foregoing it becomes apparent that laminated plastic boats have now proven their usefulness beyond question, that they can be produced far more rapidly than comparable boats of wood or steel and that their maintenance is substantially less costly. While extremely rapid mass production of these boats has not yet been attempted, there is little question that it can and, it is to be hoped, will be done in the near future.

REAR ADMIRAL C. W. DYSON, U.S.N.,

who was the last member of the Engineer Corps, still specializing in engineering duty, to remain on the active list.

# LOGISTICS AS SEEN BY A RESERVE OFFICER

CAPTAIN CARL J. LAMB, USNR

THE AUTHOR

who spent three years at the Naval Academy and was commissioned in the Naval Reserve in June, 1917, has contributed four previous articles to the JOURNAL. In addition to a long period of time in the central station and marine departments of the Westinghouse Electric Corporation, he has spent many years at sea in the Navy and Merchant Marine, and holds unlimited Marine Chief Engineers License, steam and motor, in addition to professional Engineer licenses for the states of Connecticut and Indiana. At the present time Captain LAMB is again on active duty as Supervisory Inspector of Naval Material at Houston, Texas.

Until the magnitude of the logistics problems involved became glaringly apparent during World War II, very few people in or out of our military services had a true concept of their vital importance. As the war progressed our planners soon realized that its successful outcome would be determined by our ability to provide the necessary logistic support, which, alone, could assure victory to our forces.

It is not the intent of this paper to discuss logistics or their planning, as developed during and since World War II, but to discuss certain phases of the subject as observed by a Reserve Officer in civil life. Not being an expert on the subject, the writer's only desire is to call attention to certain data and observations, mainly on lower levels, with the hope that they may cause thought and discussion.

Since returning to civil life in 1945, and based upon lessons learned from Admiral (then Vice-Admiral) Robert B. Carney, the writer has noticed and examined with an enlightened appreciation, various aspects of our national industrial life, many of which may possibly have a very direct bearing upon logistic support to our military forces in case of war. While the responsibility may rest with the National Security Resources Board, it is possible that some of the items observed may not have been observed by that Board or the interested military Logistics planners.

In the consideration of an all-out war with any potential enemy, such as Russia and its satellites, it is evident that, for the first time in history, "Total War" as such must really be waged. We are no longer a "have" nation, but depend upon world encircling lines of communication to provide an impressive amount of the minerals and vital raw materials which we must have if we are to be in a position to win such a war. The extent to which we can furnish logistic support will determine the strategy and tactics which we can employ.

The ocean transport of such raw materials requires ships, men and extensive Naval-Air protection. When we remember that our enemies will far outnumber us with respect to manpower, it becomes mandatory for us to reduce to the barest possible minimum our ocean transport along external lines of communication, in order to channel the steel, fuel oil, food and men required for such extensive movement, from non-combatant efforts.

It would be redundant to try to list here those basic minerals and raw materials which we must import in peacetime, and without which we cannot wage successful war to preserve this country. Congress, recognizing the situation, has provided for the stockpiling of some of these essential sinews of war. It is almost impossible for anyone to predict, however, what amounts of which materials will be required, over unknown periods of time. We do know that many materials will be critical, and that lack or sufficient shortages of certain ones may result in total defeat.

If we recognize this estimate of the situation to be correct, we then are in a position to seek practical solutions to the problems apparent. It is not intended here to cover the entire field, but only to touch upon a few vital elements of the overall problem, with what seems to be the simplest and most direct line of approach. Only four broad, related and important aspects of our national logistic situation will be referred to, with suggested practical solutions and examples. These are discussed under the headings of fuel, transport, power, and steel.

In considering these four particular subjects, it is quickly evident how closely they are interrelated. It is not possible for us in this country, today, to acquire one of the four in sufficient supply without ample supply of the other three. The further afield we go to obtain the raw materials to supply one, the more of the other three must be *wasted*.

*Fuels* are here classified, for discussion purposes, as oils, coals, gas, wood, waste products and water. Of all these only one, oil, has to be imported, both in peace and war times. To import oil requires the expenditure of steel, fuel oil, transport, and the Naval protection to keep the lines of communication open, which again requires the expenditure of additional fuel, steel, transport and manpower.

*Transport* is by rail, truck, ship, barge and airline. Each requires fuel, and only one, rail transport, really has its choice of two fuels, coal or oil. The cheapest form of internal transport is by barge, upon the rivers, canals, lakes, and inter-coastal waterways, and it is the only one of the transport agencies which permits the extensive use of wood, plastics, or concrete construction in place of steel. Again, barge transport requires fewer men per ton mile, and less fuel per ton mile than any other form of continental transport.

*Power* in the United States is generally generated through the expenditure of coal, oil, gas, water, and a small amount of waste products such as bagasse, sawdust, sewerage gas, etc. Only one of these, oil, has to be imported. It requires the maximum amount of steel, transport, power, and manpower to bring oil to the boiler where it is to be burned. Water requires the least expenditure of steel, transport and manpower, as a source of energy to generate power.

*Steel* is produced from iron ore, and requires one ton of limestone, four tons of coal and two tons of high grade ore to supply one ton of ingot steel, supplemented by extensive transport, power and manpower. Since we no longer have enough high grade iron ore in this country to satisfy our peacetime requirements, we are importing increasingly large amounts of ore, and are planning to import greatly increased

amounts, as our own sources decrease, and as our demand increases. The ocean import of ore requires increasing expenditures of oil fuel, more steel ships, and larger supplies of manpower.

After the above very brief review, we then wonder what we can do, constructively, to reduce the expenditure of fuel, transport, power or steel, either in emergency or war. Some of the suggestions and examples which follow may seem elementary or inconsequential, but it is believed that they may add up to appreciable savings of fuel, external transport, power, steel and manpower.

In light of present knowledge, several general rules, for possible country-wide application, present themselves.

1. Do not burn oil as a fuel, if it is economically or logistically possible to burn any other fuel. By the same token, it is self-evident that, in general, new steam or Diesel power plants to generate electricity should not be built in those localities where the potential power which may be generated by water has been completely developed. Wherever possible the saving of any form of transported fuel by utilizing local waste products should be accomplished.

2. Develop all forms of our potential inland waterway transport system to the maximum extent possible, using wooden barges where practical, thus providing cheaper internal transport because of reduced fuel and manpower requirements per ton mile, and permitting us to reduce the amount of steel requirements for rail cars, locomotives and trucks.

3. In all parts of the country not within economic logistical distance of oil refineries, recover used automotive crank case drainings, preferably by re-refining it into high grades of lubricating oil, or by burning it as fuel. This will save transport, crude oil, fuel and manpower.[1]

4. Wherever possible generate some power in municipal sewerage plants, by using the sewerage gas available.

5. Utilize all waste products possible, either in place of raw materials which require ocean transport, or as fuel.

6. Wherever possible, use wood, plastics, magnesium, titanium, glass, concrete, or brick in place of steel, iron or other strategic metals.

7. In all parts of the country not within economic logistical transport distance of a basic steel mill which makes steel primarily from ore, manufacture steel from scrap in electric furnace steel mills. This will save fuel, transport and power.[2]

It seems to this writer that the above rules are almost self-evident. They have not been generally applied in this country to any great extent in the past, because economic or logistic necessity has not so dictated. It is widely believed that, in the event of a possible World War III, we will not have a long preparatory period before heavy and decisive actions occur. We are now in an emergency, preparing against war. It behooves us to really prepare on the all-out logistic level.

Practical examples:

*Fuel Oil:* There are a few northern garages which burn their crankcase drainings in their heating boilers, thus reducing their purchased fuel by approximately 50%. There are also a very few refineries which collect crankcase drainings and re-refine them to be reused. The major oil companies run the crankcase drainings from their own trucks and cars, back through their stills, along with crude. There is still available, however, a very large supply of crankcase drainings suitable for use as fuel or as raw material for re-refined lubricating oil. The salvage of this used oil on a large scale locally would reduce appreciably the requirements of ocean, barge, tank car and truck transport, with the consequent reduction of fuel burned by such transport.

Many large cities and municipalities operate trash incinerators, city dumps, or both. The trash is just burned, or

| | Distance Miles | Barge Per Ton | Rail Per Ton |
|---|---|---|---|
| Salt | 680 | $3.50 | $6.00 |
| Iron and Steel | 850 | 3.50 | 9.40 |
| Sugar | 400 | 3.80 | 5.00 |
| Grain | 950 | 2.20 | 8.60 |
| Petroleum | 910 | 2.70 | 8.00 |
| Coal | 950 | 2.00 | 5.72 |
| Sulphur | 650 | 2.80 | 7.20 |

AVERAGE TON MILE TRANSPORTATION COSTS OF CRUDE OIL AND PRODUCTS—YEAR 1946.

| | | |
|---|---|---|
| Barges | $0.00259 | 100% |
| Crude Pipe Lines | 0.00477 | 184% |
| Gasoline Pipe Lines | 0.00527 | 203% |
| Railroad, carload | 0.01640 | 643% |
| Company-owned trucks | 0.06853 | 2640% |
| Company-owned ships* | 0.00050 | 19% |

* Note that only deep-water shipping is less costly.

used as fill. The city of Miami, whose present incinerator has become small and obsolescent, has used the trash incinerator to generate steam for a city hospital. The new sewerage disposal plant of Tampa will generate some of the power required to operate the plant by sewage gas in internal combustion engines, as does the Coney Island plant in New York, and a few other installations.

In Florida, Texas, Arizona, California, and other localities having similar climates, there has been some use of surface type solar heaters, to heat the water used in homes, and a few stores. The writer has seen such installations which have been in service 20 years or more, which have given perfect service during that time, and have supplied all the hot water needed during their life, without the expenditure of any gas, oil, or electricity. Very few of the new homes built in Florida since the war have employed such heaters, but have used mostly electric water heaters. The widespread use of solar hot water heaters, as well as of such heat exchangers designed as house heaters, feed heaters for boilers, laundries, commercial plants, etc., could bring about an appreciable reduction of fuel expenditure, with consequent reduction of transport and its fuel.

*Transportation.*

The above tables indicate how barge rates compare with rail rates in those particular fields in which they are best justified:[3]

For many reasons, inland waterways have not reached a state of development comparable with that of rail and truck transport. Inland waterways are more highly developed in Europe, and especially in Germany and neighboring states. During World War II the allies, toward the end, were able to stop practically all rail and truck transport by aerial attack, but were never able to stop operation of barge shipments via inland waterways.

The development of just two proposed waterways, the St. Lawrence Ship Canal and Power Project, and the Florida Cross State Barge Canal from Jacksonville to Yankeetown, would immeasurably improve our transportation facilities, reduce fuel consumption, reduce manpower requirements and as-

sure deliveries of essential war materials by internal lines of communication. In the consideration of the immediate construction of the Cross State Barge Canal, it should be borne in mind that this canal will afford to many interests in Florida, as well as to the nation as a whole, strategic and protective features in the event of war, which alone would justify the construction if no material peacetime commercial benefits were to follow.

*Power.* Generally, the development of power and the selection of fuels has proceeded along basically sound and economic lines. As mentioned above, however, all efforts must be made to develop completely all hydro-power available, since every kilowatt so generated reduces fuel consumption as well as transportation and manpower requirements. The outstanding example under consideration today, and which is long overdue, is the St. Lawrence Canal Power Project, which will be of tremendous value to this country and Canada, in the event of war, not only because of the power developed without the necessity of burning transported fuel, but because it will permit transport, by internal lines of communications, of vital Canadian iron ore to U. S. mills, and of Canadian petroleum from West to East with maximum efficiency.

Due to the inherently greater efficiency of large boilers and turbo-generators, as compared with small ones, all efforts should be made to utilize only Central Station Power by industry. Except in those comparatively few cases where by-product power is available because of the needs of process steam, there is no valid economic or logistic excuse for the many small, local generating plants operated by some industries, hotels, municipalities, etc. Their operation only increases fuel demands, transport load and manpower requirements.

*Steel.* As in the case of the three other principal headings discussed, volumes could be written on this subject. At present and as a matter of fact as has been the case for upwards of ten years, there are serious steel shortages. It is obvious that greater efforts should be made to use other materials in place of steel wherever possible. This indicates the more rapid development and production of Titanium, for example, and the wider use of other metals, plastics, etc., in certain applications.

In concrete structures, the steel reinforcing rods amount to approximately 40% of the weight of an all-steel structure. As a result of research and development abroad, and of interest displayed by the John A. Roebling's Sons Company, stronger concrete requiring a smaller percentage of steel reinforcement, has been employed in a large bridge in Philadelphia, in large tanks in Miami, and in large sewer piping in Tampa. While applicable only to horizontal beams, members, slabs, etc., the reinforcement consists of prestressed steel cables. It is believed that the field of use of concrete could be widened appreciably if it were moulded under fairly high pressures, having the reinforcing members prestressed under tension and the airfree concrete prestressed or formed under sensible compression. Such concrete should have physical properties approaching those of cast iron, and might even find use in place of that metal in bedplates, pedestals, surface plates, etc.[4]

Electric furnace steel mills have found wide use in the production of alloy and stainless steels. They have found limited use in the production of carbon steel from scrap. There has been, however, an appreciable production of structural carbon steel from scrap by electric furnace steel mills on the West Coast, due to the high freight rates on scrap to the steel mill and on finished steel from the mill. There are several locations in or near the United States where the construction of electric furnace steel mills to operate on

local scrap would not only be justified economically but would appreciably reduce transport requirements, and consequently, fuel consumption:

Florida—(a mill being considered for Miami)
New Orleans
Tennessee—(a mill has been authorized)
Texas—(a mill is contemplated)
Mexico—(a mill is planned)
Puerto Rico—Cuba—Hawaii—Panama

At present, while scrap is in short supply, there is much scrap available which does not move to the steel mills, because the distances and consequently the freight rates, are too high. There is much scrap steel which is not recovered. As an example, the City of Miami, in the engineering of its new incinerator, plans sorting lines, detinning equipment, and steel and paper baling presses. When in service, bottles, rags, waste paper and metals will be sorted and sold. 12,000 tons of tin cans per year will be detinned, yielding 30 tons of tin and 11,970 tons of baled steel scrap which formerly went to the city dump. Entirely aside from fuel savings resulting from the steam generator, this modern example of municipal engineering will show gross receipts of over $350,000 per year from the sales of steel scrap, tin, baled waste paper and rags. The wide-spread practice by cities and municipalities of waste recovery as planned for Miami would result in greatly increased amounts of scrap steel and tin becoming available, not to mention increased amounts of two scarce raw materials for paper and paper-board manufacture, and would in addition, reduce fuel consumption and transport correspondingly.

In mentioning steel, we cannot overlook the tremendous wartime logistical transport problems of hauling iron ore from Cuba, Sweden, Chile, Venezuela and Canada to supply American mills. A ton of steel requires approximately 2 tons of ore, 2 tons of limestone and 4 tons of coal. A ton of scrap only needs to be melted, and if done in a small mill locally, where its products can be used, greatly reduces rail transport and fuel burden, when considered on a national scale.

In the development of steam generation, the efficiency of boilers has about reached the practical limit economically obtainable. Basic design as developed by the Navy, however, has differed radically from that used by public utilities and industrial plants, in that the Navy has had to give great consideration to weight and space, whereas the weight and space requirements of land boilers seemed of little consequence, and an almost universal standard of 50,000 BTU per cubic foot of furnace volume was deemed satisfactory. This standard probably was set originally by the stokers and centrifugal forced draft blowers available. Because of the primary urge for minimum space and weight of machinery, the use of higher speeds, higher steam pressure, higher steam temperatures and the adoption of the high speed propeller blower has brought about the present Navy boiler practice, where boilers of comparable efficiency and reliability have approximately only one-fourth the weight and volume of land boilers of the same capacity, pressure and temperature. In other words, if industrial and public utility boilers were to be built to Naval standards, they would require only approximately one-fourth the weight and cost of steel and refractories, with consequent similar savings of foundations and buildings, again reflecting transportation savings. Yet, even today government agencies, including the Navy, are building stationary boiler plants to land standards, instead of to well-proven and tried Naval standards, which would result in monumental savings of strategically scarce steel. In this connection the writer proposed in a recent article

in the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS that, instead of designing and building new emergency floating power houses, as was done during World War II, we can save *all* of the steel required by hulls, and an appreciable amount of that contemplated for boilers, by installing 30,000 KW generating capacity in surplus and obsolescent *Liberty* hulls, which is made possible by using Navy boiler and machinery standards.[5]

In contemplation of a possible World War III, it becomes evident that the ability of this country to survive and win will depend upon logistic support of vital strategic plans. *Almost* enough will not be sufficient. We can surely expect a more effective submarine campaign against our ocean and coastal supply lines than was mounted during World War II. As a nation we have become aware of our shortages of vital raw materials only so recently that we have not only not considered those savings which are possible and necessary but we have done little or nothing to obtain them. We have started to stock-pile, but it is hardly possible to accurately determine how large those stockpiles should be. If our supplies of strategic raw materials and manpower are not large enough, the results may prove to be fatal.

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THE NEXT

# ANNUAL BANQUET

*OF*

## THE AMERICAN SOCIETY OF NAVAL ENGINEERS

WILL BE HELD AT

## THE STATLER HOTEL

IN

WASHINGTON, D. C.

ON

## FRIDAY, 2 MAY 1952

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PLANS ARE NOW BEING DEVELOPED. MEMBERS WILL RECEIVE APPLICATION BLANKS IN ABOUT TWO MONTHS.

# TRENDS IN DIESEL ENGINE DEVELOPMENT

E. C. MAGDEBURGER

THE AUTHOR

devoted a lifetime to the development of the diesel engine for the U. S. Navy. He was born and graduated in mechanical engineering in old Russia. Fascinated by Rudolf Diesel's concept of the "rational heat motor" while building gas engines in Germany he began his diesel career with a Russian licencee of MAN. In 1910 he came to this country and built large gas engines for Allis Chalmers Company and crankcase compression oil engines for Fairbanks-Morse Company. In 1912 he joined Busch Sulzer where a line of engines under Sulzer license was developed and submarine engines were built to power Lake submarines. Since January, 1922, he has been with the Bureau of Ships or its predecessor. Many of his past contributions to the subject were published in the JOURNAL.

The current diesel engine development all over the world is guided by the following two basic considerations:

a. Supercharging is a "must" economically, i.e., more air must be burned per cycle with consequent higher mean effective pressures. Ratings much above the mean effective pressures obtained in the past with atmospheric induction of air for combustion are now practically attainable. Reduction in size and specific weight follows the adoption of supercharging.

b. Higher thermal efficiency must also be sought by reduction of the heat rejected into final exhaust through further expansion of engine exhaust gases down to atmospheric pressure in a supplementary gas turbine. The specific fuel consumption of such a compound engine-turbine plant can be substantially reduced and its reliability of operation increased.

Combination of the above two features creates sufficient energy in the engine exhaust gases to drive a high-speed turbo-compressor unit capable of charging the engine cylinders up to a pressure of 30 psig (3 atmospheres) when operating on a four-stroke cycle. A turbo-charged four-cycle engine of these characteristics supercharged to 30 psig, with BMEP of not less than 240 psi for continuous service and a specific fuel consumption of less than 0.31 lbs/BHP/hour is now ready to be exploited by the MAN company.

A two-cycle engine takes more air to scavenge and charge the working cylinders since some of this air is wasted into the engine exhaust during scavenging, reducing resultant pressure of the exhaust gases and lowering their specific heat content and temperature, so that at low loads the turbocharger cannot any more supply sufficient air

for scavenging and charging. However, for supercharging above 30 psig (approximately) the two-cycle engine cylinder itself can supply the increased power required by such a compressor and its exhaust gases would then represent the total energy available for carrying the useful load through expansion in a gas turbine. Such a combination of a gas turbine with an opposed-piston two-cycle cylinder in the form of a free-piston gasifier is now clamoring to supersede the original diesel engine. Supercharged to 80 psig for full power, with a BMEP equal to 220 psi and a fuel consumption of 0.36 lbs/BHP/hour it represents the utmost of the two-cycle type of diesel engine and is now under development for U. S. Navy by the Baldwin-Lima-Hamilton Corporation.

How can such heavy thermal loads be carried without damage? In the four-cycle engine such as the MAN the combustion gases are positively displaced by the upward moving piston except for the small residue filling the combustion space. All of the supercharging air is cooled and only a small amount of it is wasted on blowing out or scavenging the combustion space prior to charging the cylinder with this cooled air during the following downward stroke of the piston. This apparently is adequate for carrying continuously a BMEP of 240 psi. In the gasifier on the other hand a BMEP of 220 psi can be carried on a two-stroke cycle, or a thermal load, substantially twice as high, before the temperature of the gases exceeds the 1250°F limit for the turbine blades. The reason for this excellent endurance lies no doubt in the use of a large quantity of higher compressed air to cool the interior surfaces of the power cylinder, a quantity limited only by the BMEP of the power cylinder, which at all times must equal the MEP of the compressor times the ratio of their effective piston areas.

On the other hand, the development possibilities of the conventional two-cycle engine are strictly limited, primarily by the low efficiency of its scavenging, i.e., by the residue of combustion gases remaining in the cylinder, polluting the air charge and raising its temperature. In this respect the uniflow scavenging where the air is not required to change its direction of flow is the most efficient and particularly in slower speed engines with long strokes. These latter engines can be effectively scavenged with minimum of scavenging air hence require a minimum of fuel for it and therefore have the lowest fuel consumption. But the rating of any two-cycle engine does not exceed a BMEP of 100 psi and even this rating cannot be reliably obtained in short stroke engines of higher rpm. The scavenging blower in all conventional two-cycle engines is mechanically driven, i.e., it deducts from the power delivered to the shaft and requires additional consumption of fuel. Hence a conventional short stroke two-cycle engine, favored for the simplicity of its construction, can not possibly compare in either specific output, i.e., in BMEP rating, or in thermal efficiency, or fuel consumption with the turbocharged four-cycle engine at the present state of its development. The two-cycle engine recovers its relative advantages only when very high supercharge pressures are used and the air used for scavenging is not wasted but, heated by the scavenging process, it is usefully expanded in a gas turbine. Such is the case of the compound gasifier-turbine combination.

A naval propelling plant by its very nature must have a high BMEP rating to produce compactness and permit a maximum output in the space available and a low fuel consumption to better utilize the fuel supply which can be provided. It is fortunate for the Navy that a railroad locomotive requires a power plant with similar characteristics so that the development of one automatically advances the other.

# MANAGEMENT BY EXCEPTION—THE NAVY WAY

## Industrial Engineering in the Fleet

COMMANDER JOHN A. HACK, U. S. NAVY

THE AUTHOR

Is a graduate of the US Naval Academy at Annapolis in the Class of 1935. After varied naval service he received post-graduate instruction and completed a course in Management and Industrial Engineering at Rennselaer Polytechnic Institute in 1950. There, to quote Commander Hack "I learned the importance of the principles I have tried to outline in simple fashion for my friends who have not had the fortune to learn formally, but still desire to cure some of the Navy's "old ills."

*Management—"The act or art of managing; administration; guidance; control."*
*—Webster.*

Captain Michael O'Shaugnessy, United States Navy, did not believe in the Little People that once rolled and frolicked in the green lands of his ancestors. Certainly, at least, the leprechauns did not exist on his ship, the USS *White Mountains*, whose motto "Destroyer Service—with a smile" had been through the years both a fetish and a misnomer. In his year as Commanding Officer he had come to accept the fact that a repair ship had an awesome task. Ships came alongside with a never-ending stream of work requests. No two seemed to be quite the same.

Arrival conferences were held with the Destroyer captains during which time the work to be accomplished was discussed in a manner which sometimes bordered on the nebulous. Inwardly, O'Shaughnessy had been completely frustrated at the inability of his Repair Department to explain why, after so confident a beginning, destroyer overhauls soon became a maddening adventure, with every shop working frantically to complete all of the accepted work, which slowly but inevitably got beyond the capability of his ship to finish on time. The *White Mountains* was a fine tender by the standards of the Fleet. She accepted, and completed, more work requests than any other in the Atlantic or the Pacific. But as each destroyer cast off its lines, left in the wake of her churning propellers were many sorry memories . . . jobs which the tender had promised to do but which had been terminated for "insufficient availability," "Material not available,"

"beyond the capacity of the tender to accomplish" . . . logical reasons of course, but so intangible to grasp, or to explain to the Destroyer captain who was now a dissatisfied customer.

It was as though a factory were accepting orders from customers, with solemn assurances of delivery, and then in the short space of two weeks apologizing that the factory couldn't make those things after all. O'Shaugnessy knew that there must be some escape from this weekly routine of frenzy. But he had come to accept it too, as a natural thing that must be, in repair ships or Navy Yards.

Such were his thoughts as he was startled by that voice from the vicinity of his cabin door. It seemed as though he were hearing that a problem would be developing tomorrow. There were very specific reasons for it. Very clear-cut choices of decisions were being offered for consideration. No, he didn't believe in the Little People of Ireland, but the thought of so much advanced warning of a problem that didn't even exist as yet both intrigued and startled him, to say the least.

## THE MANAGEMENT ENGINEER

Lieutenant Commander Jones was no leprechaun. He was not little, nor was he Irish. Although his precise exposition of the coming problem, its causes and the choice of decisions needed to overcome it, had seemed almost like a prophecy, it could not be claimed that he was even a genii. He was just an average officer with a burning desire to see more things produced at a minimum cost and in the shortest possible time.

Jones, just recently ordered aboard as the new Repair Officer, appeared to know a little about every phase of the industrial field, yet was an expert in none of the traditional engineering crafts. One might describe his talents as being but a state of mind, as he inquired into a galaxy of events which outwardly bore no relation to each other and attempted to connect their interlocking facets. With the fervor of a monastic, and the mysterious aid of charts and diagrams, he was a study as he strove to devise means of producing more things, more quickly, with less effort and expenditure of money, and as automatically as possible. So commonplace were his methods and techniques, that the people about him suspected that he was employing only common sense in his explanation of the world's and his ship's problems and their solutions.

Yet his civilian counterparts commanded fantastic salaries as consultants in furthering American mastery of industrial organization and production methods. To the Navy, he was a newcomer, a Johnny-Come-Lately, whose position was by no means established. The Electronic Engineer, The Naval Constructor, The Metallurgist . . . even the Radiological Engineer all fit into a nice precise niche in the Navy's system. But the Management Engineer fit into no such precise niche. Bringing together such a kaleideoscopic welter of problems. . . . Psychological, organizational, financial, statistical, geophysical, those relating to production and sales . . . that he belonged to no one, but was useful to most of the established units of the naval establishment. As he pursued his art, a wake of heated discussion was left behind, for efficiency and improvement always necessitates clear-cut responsibilities to produce. From these discussions some improvement always resulted.

Jones was, in a sense, one of the Navy's living memorials to the great

James Forrestal . . . being one of the Navy's Management and Industrial Engineers. It has been said that during the last war Mr. Forrestal, after a tour around the Navy's industrial establishments, and after hearing some of the commonplace complaints of business men concerning the average Naval Officer's inability to appreciate the problems and philosophies of private industry, conceived the idea of training a nucleus of career officers in the art of industrial management. Through them, as they pursued their careers in Shipyards, in the technical Bureaus, or in positions where the Navy must coordinate its efforts with those of industry, Forrestal foresaw a blending of the techniques and philosophies which made America industrially great, with the courage and traditions of the naval establishment. Both the Navy and industry could prosper with the efficiency bred from a sincere mutual understanding.

A handful of officers, Jones among them, had been sent back to college to learn the industrial dogmas. The University had loaned some of them to a small refrigeration corporation as consultants, to further their first-hand knowledge of American Industry in a company which was by self-admission sick from the postwar period of decreasing profits. The officers had been taught by the managers of a large steel corporation as part of their training. And then, like disciples, Jones and his classmates, had scattered throughout the Navy, preaching the gospel of industrial efficiency and the philosophies of America to whomever would listen.

After he had come to the *White Mountains*, Jones had visited in O'Shaugnessy's cabin from time to time, and over several cups of coffee discussed one small phase of that newfound faith, the problem of organizing a Repair Ship to think, act and produce along modern American industrial principles. The burden of his talk had been:

"We can't create a Utopia overnight, of course. There will be resistance to any system which is a change. But by common sense methods and persistent education of the Repair personnel in the techniques of efficient production planning and control we should be able to bring the tender to a state of efficiency which would compare favorably with the small job order factory of which she is a military counterpart. We should have a system by which the orders of our customers are analyzed in such a manner that we may plan, produce and deliver the repairs that they desire in the time allowed for such operations."

## THE NORMAL CAPACITY

"The first step in such a system would involve the determination of the tender to accomplish work. It is logical to presume that the capacity of each of the shops could be measured in common productive units. Since time and time again, machines have been idle for lack of men to work them, one criterion of a shop's ability to produce work would be the number of men assigned to the shop and the amount of time they can spend in working. I find that in the past each man in the Repair Department has been engaged in work on destroyer repairs approximately six hours every working day. The other hours inevitably disappear in the daily military drills, watches, lunch periods, and the other interruptions which are a part of military life. Each shop can be said to have a normal capacity to do work of six man hours times the number of men assigned. This can be considered to be the standard of achievement which can, and must, be achieved in a normal working day."

### EXPRESSION OF WORK IN TERMS OF THE STANDARD

"If work requests submitted by a destroyer customer were to be so analyzed that each shop's operations necessary to accomplish the job as a whole were to be expressed in man hours also, it would be possible to establish a primary basis for determining which jobs can be accomplished, and which cannot, long before the overhaul of the destroyer commences. A shop should be able to accomplish an amount of work equal to her capacity in man hours. Only when a shop has been allocated work equal to her capacity to accomplish repairs, can she be considered to be operating at full efficiency."

### THE JOB ORDER

"The Destroyer Officers are the customers of the repair ship. They know what they want accomplished and express their desires on a Work Request form so well established by usage that, given the ability to write, and the patience to fully describe the repair required in sufficient detail that a third party can understand their desires, every officer can accurately fill out a Work Request. For instance, the Commanding Officer of the USS *Tinplate*, desiring the tender to install a certain electronic device, might write out a Work Request simply:

" 'Accomplish ShipAlt E422.' "

"The tender Repair Officer must translate this request so that it may be understood completely by every workman who will be engaged on this particular job. The translation should describe not only what is to be the end accomplishment but a decision as to the most efficient, or practicable way to do it. It should explain who is to do each operation, what they are to do, when they are to do it, and how long they may spend on the operation required. If the features of the work are such that a particularly skilled man is required, that fact should be noted. With the assistance of his Warrant Officers, the Repair Officer could translate incoming work requests into job orders which meet the requirements outlined above. A typical job order, prepared from the preceding work request, and prepared with sufficient copies for every interested shop or officer to receive one might appear as in Figure 1.

"Filled out thus far this form has explained the operations to accomplish the entire job, has established the man hours required to accomplish each operation. In the hands of the Production Planning Officer it will become the basic document from which he may direct the operations of each shop, to the end that all will work with complete coordination, and at their full normal capacity."

### MATERIAL AVAILABILITY

"The Job Order would be useful only if the material required became available in the appropriate shop at the time when the work was to be accomplished. Too many times plans proceed without taking this rather obvious fact into consideration. After he has filled out the Job Order, the officer investigating the work should also fill out a Bill of Material, or at least should indicate that material which is required, and is not carried in stock as a matter of routine. Figure 2 is an example.

"Now, armed with a job order with each operation described in units of ship's capacity, a Bill of Materials, and the original work request, the Repair Officer could proceed to coordinate the work required in each of his shops during the entire period of the forthcoming overhaul."

## USS *White Mountains* JOB ORDER

Ship. *TINPLATE* W.R. *1–51* Investigated by: *A.B.Sea*

Material Required ☐ *Is on Board* ☐ Is on order Delivery Date

| Shop or Office | Operation | Hours Required | Days Req. | Day Start | Day Finish | Actual Hours |
|---|---|---|---|---|---|---|
| Ship to Shop | | | | | | |
| Shipfitter | Manufacture and install Aluminum Stub Mast as per BuShips Plan S–859221 | 90 | | | | |
| Electrical | Install Electric Cable as per Buships Plan S–859222 | 18 | 3 | | | |
| Electronic | Install Device Able. Connect up and test. | 6 | ½ | | | |

Work Inspected by Ship..... Work Accepted by.....

DD W.R. No. *1–51* *WHITE MOUNTAIN* J.O. No. *19–51* This copy to: *SHIPFITTER*

FIGURE 1.

## *White Mountains* BILL OF MATERIAL

U.S.S. *TINPLATE* *15 February 1951*

Deadline Delivery Date Required by: *A.B. Sea*

| Std. Stock Cat. No. or Class No. | Description of Article | Unit | Required |
|---|---|---|---|
| 62–S–9588 | 1″ Aluminum Tubing | 1′ | 75′ |
| 84–S–8655 | 3 conductor shielded cable | 1′ | 400′ |
| 89–P–8744 | Device Able | 1 | 1 |

Date submitted to Supply Officer

Date furnished by Supply Officer

DD W.R. *1–51* *WHITE MOUNTAINS* J.O. *19–51*

FIGURE 2.

## PLANNING—A FUNCTION OF TIME AND CAPACITY

"Some systems progress this far and, failing to recognize the relationship of time to capacity, leave the final result as confused as though the entire planning process had been based upon experience alone. During the early part of the last war submarines were sent in to a new shipyard on the west coast. Their work requests were analyzed well in advance, translated in such a manner that all jobs could be accomplished in the sixty-day availability period, as proven by a comparison of the capacity of the shops and the man hours required to do the work. But, at first, no submarines were able to leave the yard at the end of the scheduled availability. Excuses were made which were difficult to track down. Finally, by charting each operation on a calendar chart for every work request, showing the detailed operations required, the shop involved, and the time each shop required on each operation, the interrelationship of all jobs to each other was visually demonstrated. For as everyone knew, but no one recognized, certain jobs could not be started until others were finished. And while the preliminary estimates did not overload any one shop over a sixty-day period, many shops were overloaded in short periods of time. Moreover, a delay in one operation, though it was early in the overhaul, caused a series of delays down the line, until just before the sixtieth day the cause was not only forgotten, but could never be determined. Shops which were operating efficiently were blamed for delays that were caused by inefficient ones, simply because they were the last to work and so 'Obviously were holding up the completion of the submarine.' Not until all shops were coordinated in time, as well as in overall capacity, by diagramming an entire forthcoming overhaul on a calendar chart, could the Shipyard Commander gain a clearcut picture of what had been happening, and a full realization that a delay on the second day was just as vital and as serious as one on the fifty-ninth day. Armed with this information, all overhauls thereafter were scheduled in advance, and in detail on a time chart, and submarine overhauls proceeded according to scheduled availability in most instances. When they did not, the Shipyard Commander knew exactly why not."

## SCHEDULING

"Just as the Shipyard was able to schedule the work on a submarine in advance of its overhaul, the Repair Officer could schedule the detailed operations required for each job required on the destroyers soon coming alongside. This responsibility he could place upon one of his assistants, the Production Planning and Control Officer. In the same manner as a jigsaw puzzle takes shape, the schedule would be assembled by fitting the data from each job order onto a Production Schedule Board in such a manner that the most efficient manner of utilizing the capacity of the shops, at the time most appropriate, to insure that all of the work which was within the capacity of the tender to accomplish technically, from a standpoint of man hours, and from a standpoint of total time, would flow through the shops at the proper time. For instance, he would schedule the job we have previously discussed on a large plexiglas board as follows:

## USS *White Mountains* SCHEDULE AND CAPACITY BOARD

| Shop | Daily Capacity | Daily Capacity Value one Sub-line | March | | | | | | | | | | | | | | | | | etc |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 M | 2 T | 3 W | 4 T | 5 F | 6 S ½ | 8 M | 9 T | 10 W | 11 T | 12 F | 13 S ½ | 15 M | 16 T | 17 W | | | |
| Shipfitter | 36 | 12 | ← | — | — | 19 | — | — | — | → | | | | | | | | | | |
| Electrical | 12 | 6 | | | | | | | | | ← | 19 | → | | | | | | | |
| Electronic | 12 | 6 | | | | | | | | | | | | 19 ↔ | | | | | | |

NOTE: Each job is scheduled as a line, the length of which represents the man-hours required, and thus establishes the days required.

The number on the line indicates the Job Order Number for identification.

Jobs which may be done simultaneously in a shop are scheduled by utilizing the subdivisions under each day.

Jobs which must be started only after another is finished must be scheduled on the following day.

Under Saturday the notation ½ indicates a half working, or ½ capacity day.

### ISSUING WORK AND ORDERING MATERIAL

"With the schedule in front of him, the Production Planning and Control Officer may now proceed to order material and issue work. By filling in the deadline delivery date on the Bill of Material and passing this slip to the Supply Officer, the latter may take such action as is required to insure delivery of needed material by the specified date. The Production Planning and Control Officer can also complete the Job Order by filling in the day to start, and the day to complete, each operation. The completed Job Order, when delivered to

the appropriate shop would constitute an order to proceed on the work, on or before the date specified. Blue prints, the original work request, Bill of Material, and other appropriate data should be stapled to the Job Order when issued to the shops."

SHOP PLANNING

"Since each job's operation would be a separate entity of work, insofar as the officer in charge of each shop was concerned, it should be noted that any system of priority numbers assigned to the jobs as a whole would be meaningless. The shop which had to 'install, connect up and test Device Able' in the work under discussion would be misled if it were told that this were a priority 1 job. For in the Electronic Shop it has no importance until the Electrical Shop has completed its work. By placing Job Orders in a Shop Folder, in order of Day to Commence, the priority of job orders within the job would be automatically established. Unless some unusual situation should arise, the shop would proceed on work in the order that the Job Orders had been filed, that is, on specified dates. Regardless of how much, or how little importance the job under discussion is, it must start in the Shipfitter Shop on 1 March, in the Electrical Shop on 10 March, and in the Electronic Shop on 13 March."

"In order that the Officer in Charge of a shop, as well as all the personnel might have a visual picture to assist them in their planning a 'Load Board' should be placed in a prominent location in the shop. As each Job Order is received appropriate data should be entered on the Board, which thereafter would serve both as a goal to accomplish as well as a visual trouble indicator."

"A Load Board might well appear:

USS *White Mountains* ELECTRICAL SHOP

TODAY IS *11 March*

Capacity Today *12* Man Hours

Schedule Today *6* Man Hours

Capacity This Month *90* Man Hours

Schedule This Month *60* Man Hours

| Ship | JO Number | Est. Man Hrs. | Schedule Start | Schedule Complete | |
|---|---|---|---|---|---|
| *Tinplate* | 19 | 18 | 3–10 | 3–12 | |
| | | | | | |

NOTE: Mark jobs which are late in red under "Schedule complete and Schedule Start."

"The Shop Officer looking at his board could see that the shop was not scheduled to capacity, either on this date or for the rest of the month. He can see at a glance that the only job in the shop is progressing on schedule. The shop personnel could also note that this was a 'light day' and the remainder of the month was, at the present time, scheduled to be a light month. If the tender itself had repair work to be done, the Officer in Charge could divert some of his shop personnel to assisting in that work. Perhaps he could allow some of his men extra time off to repay them for overtime work in the past.

Individuals might take this opportunity to ask for an afternoon off to accomplish the personal chores that plague Navy ships and installations. If the work scheduled were more than the normal capacity of the shop, the Shop Officer as well as all the personnel would realize that overtime work was required. Personal problems would have to be put away for the day. The load board could serve as an excellent aid for the Officer in Charge of the Shop to plan his work program and to help him in his personnel administration work."

### THE ARRIVAL CONFERENCE

"The preceding could be completed before the destroyer came into port and tied up alongside the tender to commence her scheduled overhaul. As soon as practicable, the officers from the destroyer and the tender could meet in an arrival conference in order to discuss the few items of work which could not be planned without amplification, or which were in the nature of an emergency in that they had just come to light. With the 'Schedule and Capacity Chart' before him, the Repair Officer could speak with full authority and confidence on every item of work under discussion. He could visually demonstrate why he could or could not take on more work. Alternative decisions might be discussed, if the destroyer captain desired to take back orders for one job and submit another. The tender might have to go to overtime in order to give itself more capacity for a short interval of time. Of course it must be fully understood that such could not become 'routine' otherwise the morale of the tender forces would be vitally affected. Both parties could leave the conference with a complete visual understanding of the work items which could be accomplished, and with full confidence that they would be done. Not only would they be shown to be within the technical capacity of the tender to accomplish, but they would be within the man hours capacity at every instant of time as well.

### PRODUCTION CONTROL

"A Management Engineer cannot of himself produce work. Neither can he assure anyone that plans which appear to be sound technically will remain so. Given incentives, personnel will work faster than estimated. Thwarted with real or imaginary grievances they may work slower. Emergencies may, and in the Navy, often do arise. The Repair Officer should be assured that any deviation from the plan will be called to his attention immediately, automatically, and without being bothered with the many routine items of work which are proceeding according to schedule, and therefore of no concern to him. His Production Planning and Control Officer should institute a system which would allow him to manage by exception... that is to be asked to make decisions,and to devote the maximum of his efforts, to those matters which are exceptions in that they are not happening as planned."

"The Planning and Control Officer could accomplish this by setting up a Production Control Board, listing those items of work which are of importance to the success of the overhaul, to the

desires of some senior officer, or which he senses may cause trouble."

"He would realize that the job under discussion, Work Request 1-51 from the *Tinplate* was a critical job since his schedule board warned him that only by perfect coordination could it be completed in time, in the 13 days allowed. He could control this and other jobs by setting a board up with the following characteristics:

USS *White Mountains* PRODUCTION CONTROL BOARD

| SHIP | WR | JO | This work is now in the location indicated | | | | This work is now scheduled to move from present location on date indicated and must be completed on date indicated | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Supply | Ship Fitter | Elect | Electronic | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 16 | 17 |
| *Tinplate* | 1 | 19 | | ● | | | | | | | | | ● | | | | | ● | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | |

NOTE: Place a blue pin in the appropriate location to indicate satisfactory progress.

Place a red pin in the appropriate location to indicate unsatisfactory progress.

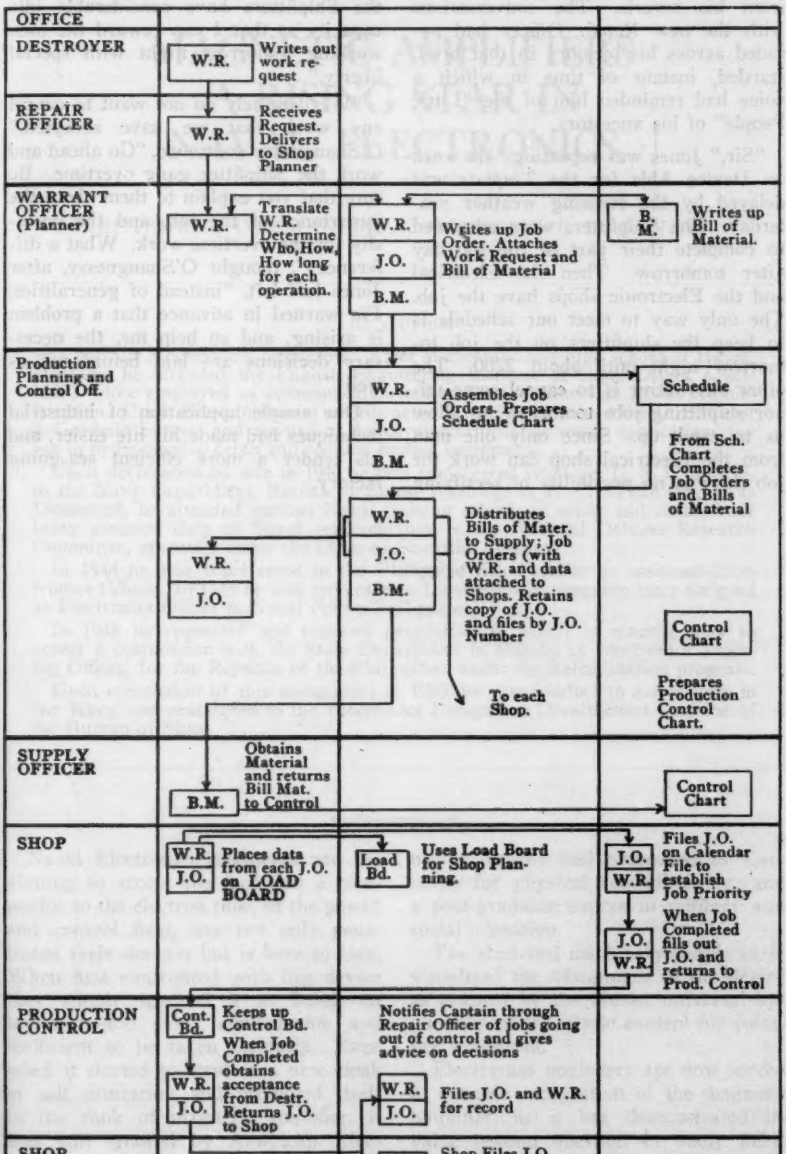
Place a green pin in the appropriate location to indicate scheduled completion date.

"Each important Job Order would be visually depicted, in such a manner that the Repair Officer could see each operation happen, or be warned if it did not happen on time. When material was received aboard the Supply Officer would return the Bill of Material to the Repair Office. As each shop completed its operation the appropriate copy of the Job Order would be returned as a signal that the operation was completed and the job had moved on to the next shop. By placing blue pins on jobs which were progressing satisfactorily, and red pins on those which were not, immediate attention would be drawn to work which was endangering the success of the overhaul. By immediate investigation the causes of the trouble might be learned, and by inspection of the schedule chart the effect on other jobs and possible remedial actions which are necessary might be determined."

"Through the development of such a system one art of the Management Engineer has been practiced. A simple system of production planning and control, so depicted that plans may be made visually and troubles spotted almost automatically."

"Here, now, in review is a diagram of my plan":

FLOW DIAGRAM OF PRODUCTION PLANNING AND CONTROL SYSTEM.



Captain O'Shaugnessy was disturbed from his reverie. The conversations with the new Repair Officer had paraded across his memory in that brief, startled, instant of time in which a voice had reminded him of the "Little People" of his ancestors.

"Sir," Jones was repeating, "the work on Device Able for the *Tinplate* was delayed by the freezing weather yesterday. The Shipfitters were scheduled to complete their part of the job day after tomorrow. Then the Electrical and the Electronic shops have the job. The only way to meet our schedule is to keep the shipfitters on the job tomorrow night until about 2200. The other alternative is to cancel some minor shipfitting jobs tomorrow, to allow us to catch up. Since only one man from the Electrical shop can work the job there is no possibility of rectifying the delay from that angle. Next week the Shipfitters have considerable idle capacity so that I can reward the men working tomorrow night with special liberty."

"We definitely do not want to cancel any work that we have accepted." O'Shaugnessy continued, "Go ahead and work the Shipfitter gang overtime. Be sure that you explain to them about the importance of the job, and the necessity for the overtime work. What a difference!", thought O'Shaugnessy, after Jones had left, "instead of generalities, I'm warned in advance that a problem is arising, and so help me, the necessary decisions are laid before me as well!"

One simple application of industrial techniques had made his life easier, and his tender a more efficient sea-going factory.

# MAGNETIC AMPLIFIERS A RISING STAR IN NAVAL ELECTRONICS

LIEUTENANT COMMANDER A. M. VINCENT, U. S. NAVY

THE AUTHOR

was born in Montevideo, Minnesota. After elementary and high school at Havre, Montana, he attended the English Engineering Institute at Riga, Latvia (1921-1923) while employed as communication officer for the American Relief Administration. Upon disestablishment of this activity in 1923 he joined the U. S. Coast & Geodetic Survey, and assisted in the development of electronic applications for use in hydrographic depth and position finding equipments.

Upon declaration of war in 1942 he was transferred from the U. S. C. & G. S. to the Navy Department, Bureau of Ships, Washington, D. C. While serving as Lieutenant, he attended various Naval training schools in sonar and radar, later being assigned duty as Naval representative to the National Defense Research Committee, operating under the Office of Scientific Research.

In 1944 he was transferred to the Philippine Sea Frontier as assistant Electronics Officer. In 1945 he was promoted to Lieutenant-Commander, later assigned as Electronics Officer to Naval Forces Philippines.

In 1948 he requested and received permission to revert to inactive duty to accept a commission with the State Department in Manila, as Electronics Training Officer, for the Republic of the Philippines, under the Rehabilitation program.

Upon completion of this assignment in 1950, he was recalled to active duty in the Navy, and reassigned to the Electronics Design and Development Division of the Bureau of Ships.

## INTRODUCTION

Naval Electronics engineers are beginning to accept the fact that a competitor to the electron tube, in the power and control field, has not only penetrated their domain but is here to stay. When first confronted with this device they simply ignored it as being an impostor—too slow, cumbersome and inefficient to be taken seriously. Even when it started to strut in a new cloak of self saturation and promoted itself to the rank of magnetic amplifier, it was still ignored by American Electronic engineers. The device finally gave up in disgust and proceeded to Germany for physical reconditioning, and a post-graduate course in military and social education.

The electrical machinery people early visualized the advantages of the device as attested by the almost universal application of this static control for rotating equipment.

Electronics engineers are now forced to concede recognition of the magnetic amplifier, as it has demonstrated its value beyond question in many fields previously dominated by electron tubes.

The significance of this development in relation to Naval engineering is better appreciated when it is realized that this component is applicable to almost everything that rotates or moves on a fighting ship—from throttle controls on the main engines—to speed, frequency, voltage, current and temperature controls on auxiliary equipment—fire control, servo mechanisms, and stabilizers for guns, radar and sonar equipment—pulse forming, sweep multivibrator circuits for radar, loran, and transponder equipment, to computers, course and speed plotters to verify the results.

The device is ideally suited to submarine and aircraft equipment because of the extreme voltage fluctuations of the prime power sources. Numerous countries have contributed to its evolution.

## HISTORY

The magnetic amplifier is not new—the principles of the saturable core control were used in electrical machinery as early as 1885 although they were not identified as such.

Saturable core devices have been used, principally in heavy electrical machinery, in the United States since 1900. The U. S. Navy has been using them to a limited extent mostly as static control instruments in rotating equipment during the past eight years; development beyond this perimeter into the electronic field has been retarded in the United States primarily due to the reluctance of our engineers to experiment with a new device, especially in view of the excellent performances experienced with current electron tube equipment.

Many engineers are under the impression that the Germans invented the magnetic amplifier; actually it is an American invention. The Germans simply took our comparatively crude device, improved the efficiency and response time, reduced weight and bulk, broadened its field of application, and handed it back to us.

It was mainly the improvement in processing magnetic material and the introduction of selenium rectifiers that led to the wide use of the magnetic amplifiers by the Germans.

The German navy used the device in its master gun stabilizers; their air force used it in automatic pilot and ground approach systems. They also used it in servo and frequency control systems for long range rockets, blind landing aids, and to regulate the fuel flow in relation to atmospheric and ram pressure in some types of guided missiles. They also applied the device as cathode followers, replacing electron tubes in computer circuits. The German army had started to apply it to the V-2 rocket stabilizer and steering system.

German civil interests were also quick to visualize the advantages of this device. They had started to apply it to computing machines, electric brakes for trucks and locomotives, high voltage power lines (controlling up to 50.000 KVA), a-c streetcar controls and other miscellaneous uses.

The fact that the Germans introduced the device into fields previously dominated by electron tubes is considered by many to be of as great importance as the technical development of the device.

Although Germany is unquestionably responsible for the rebirth of the magnetic amplifier, other countries (especially the United States) held a considerably greater number of patents on this device. The efforts of Sweden, England, and Japan were also considerable.

The reason for the Nazis assigning their best scientists and expending millions on its development in the midst of a bitter war has never been definitely

determined. There was no shortage of electron tubes; performance of the tube-controlled equipment certainly was not improved by the substitution of this device.

Considering the above, the motive warranting such expenditures appears to have been an acute shortage of field electronics technical personnel, making a dependable, maintenance free device mandatory wherever possible.

The performance of the magnetic amplifiers obviously must have equaled that of the electron tube circuits as these devices were used in some very critical applications, such as stabilizers, servos, and fire control equipment in their finest fighting ships.

It was during the last war that the U. S. Navy started to exploit the device for purposes other than power regulators. Development contracts have now expanded into the high speed range of digital computers and pulse forming, memory and scanning applications in radio, radar and sonar equipment.

## FUNDAMENTALS

A magnetic amplifier is simply another type of control valve. A valve in a water line can be considered an amplifier, if a small stream of water operates a larger valve in the main line.

Electrically the device can be compared somewhat to that of an electron tube, in that the grid of the tube controls a relatively large amount of plate power. In a M/A, power is varied, like the water valve and the tube, by inserting the device in series with the load to be controlled. Control is then accomplished by varying this impedance, which increases or decreases the power to the load. The impedance to the flow of AC is effected by changing the degree of saturation with a relatively small amount of DC, or properly phased AC, through a separate winding on the same core. An unsaturated core has a relatively high impedance to AC. A saturated core acts effectively as an air core, with practically no impedance except for the ohmic resistance of the copper wire.

Figure 1 illustrates the principle of operation. With the core completely within the coil the impedance to the flow of current is high—permitting possibly only a fraction of a volt to appear across the load. Pulling the core out causes this load voltage to rise progressively to practically 115. In effect

Figure 1

this is the operating principle of a magnetic amplifier. Since it took only a few watts of muscular energy to move the core within the coil, which may in turn control several horsepower, the device is an amplifier. Since this is done magnetically, the device is called a magnetic amplifier.

Technically, it may be decribed as essentially a device which controls the a-c reactance of a coil by controlling the effective permeability of the magnetic material upon which the coil is wound.

Although the sketch in Figure 1 is drawn primarily to illustrate the principles of operation, there are many applications still in use utilizing the mechanical system. The principle of control is the same; the action, however, does not completely fulfill the description in the previous paragraph "controlling the effective permeability of the magnetic material" since iron in this instance is actually replaced by

air. In modern applications the core is stationary; its impeding effects to a-c power is changed by varying the saturation of the iron core. This not only simplifies the installation but permits a much higher speed of response and considerably widens the range of applications.

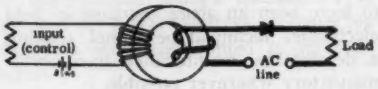
Figure 2(a) is the basic circuit of the saturable control. The secondary or load winding impedance is controlled by the amount of current flowing in the primary or control winding. This would be a relatively inefficient amplifier because the control winding ampere turns must be equal to the load A/T plus sufficient A/T to saturate the core.

In Figure 2(b) a rectifier is inserted in series with the load. This results in unidirectional load current which assists the control winding in saturation. Considerably less control power is now required, making the device highly competetive with other types of amplifiers. Since the control power is now less than the power controlled, the device becomes a high-gain amplifier; more specifically an internal self saturable magnetic amplifier.

Although Figure 2(b) has been developed into a high gain amplifier, it is still deficient in some respects, namely:

1. The device as shown would act as a step up transformer in reference to the load power, and generate power into the control winding. This would not only be undesirable but would result in a considerable waste of power.

SATURABLE REACTOR
Fig. 2(a)




MAGNETIC AMPLIFIER
Fig. 2(b)

2. Due to the single rectifier, only an inefficient pulsating DC load power would result.

Figure 3 shows a more practical design. (To simplify the sketches, cores will be taken for granted, control windings will be represented by a single turn.) With two load coils they can be wound opposed, neutralizing any transformer effect into the control coil. The two power coils also permit utilization of both sides of the alternating current, resulting in good wave form and efficiency. Figure 3(a) is the basic amplifier for AC loads. With the addition of two rectifiers, (3b), the device generates and controls a DC load from an AC supply. Three-legged cores, with the control coil wound on the center leg, and power coils on outside, are usually used with the above circuits in power control applications.

## BASIC CIRCUITS

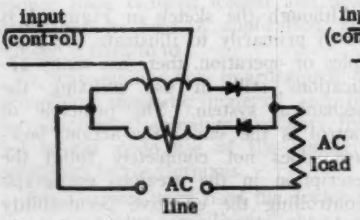



Fig. 3(a)

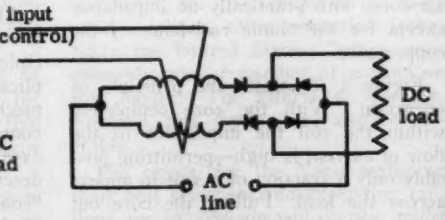



Fig. 3(b)

COMPOUND CONTROLS

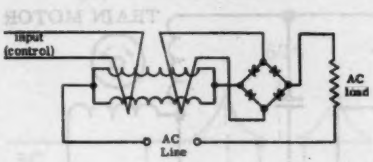



Fig. 4(a)

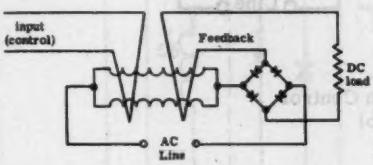



Fig. 4(b)

Figures 4(a) and 4(b) show further developments with the addition of feed back. These are identified as external feedback. Gains up to several million per stage have been obtained with these circuits.

Figure 5(a) is a sketch drawn originally for school purposes showing how this amplifier can be used without the load power passing through a rectifier; (b) applied to variable speed reversing motor.

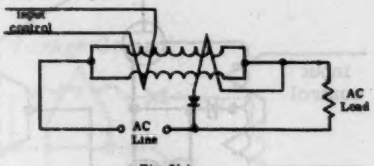



Fig. 5(a)

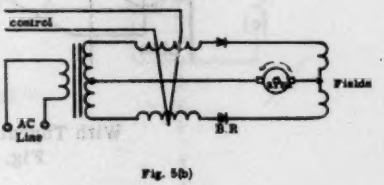
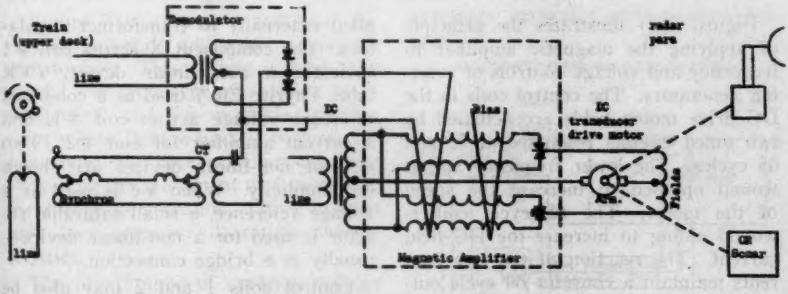



Fig. 5(b)

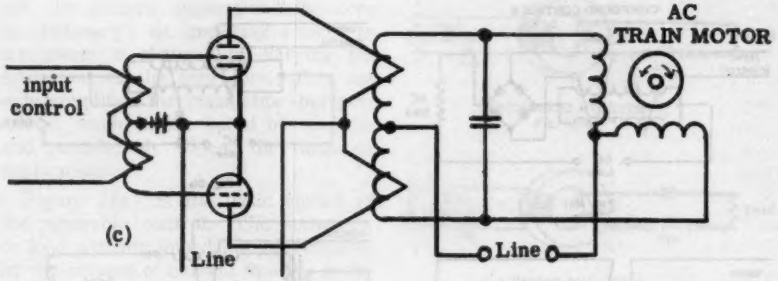
Figure 6 contains schematics showing applications to training schemes in servo systems. (a) is a sketch of a servo system utilizing magnetic amplifiers to replace an amplidyne. (b) shows a standard thryatron training control drive. (c) the same circuit modified for magnetic amplification. The thyratron conversion is relatively simple as most of the components designed for this tube will also match the magnetic amplifier. This conversion can almost be simplified to the extent of providing a rectifier adopter to plug into the thyratron tube sockets.

SERVO SYSTEMS
SERVOMECHANISMS

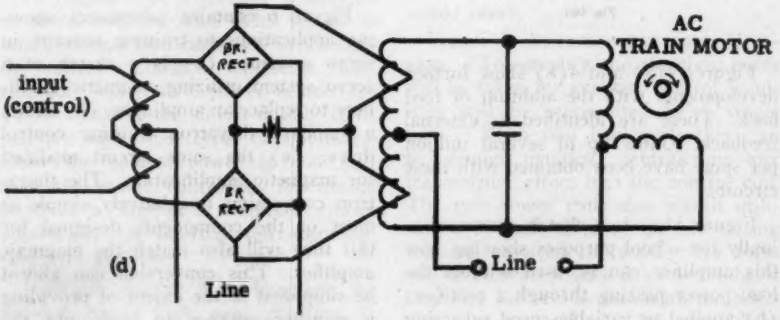



SERVO CONTROL WITH DC SERVOMOTOR

Fig. 6(a)




**With Thyratron Control**
**Fig. 6(b)**



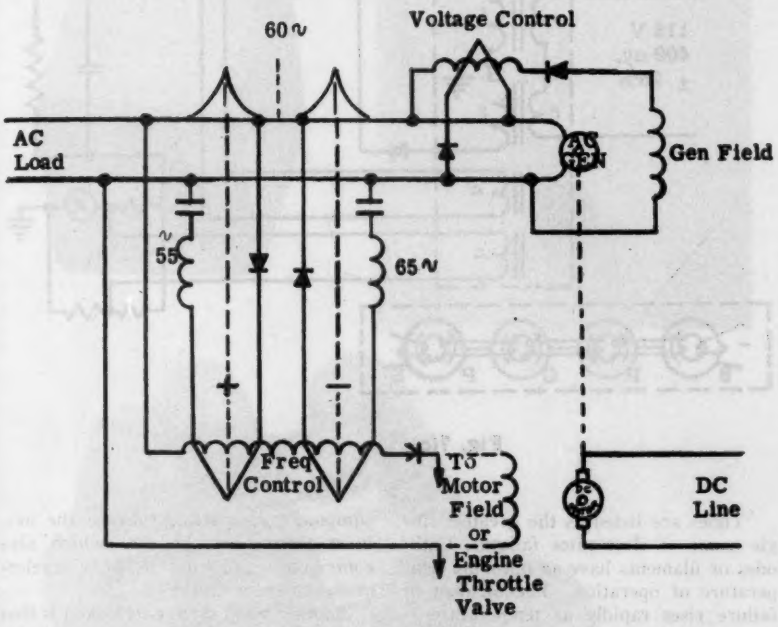

**Magnetic Amp. Conversion**
**Fig. 6(c)**

Figure 7(a) illustrates the principle of applying the magnetic amplifier to frequency and voltage controls of rotating generators. The control coils in the DC drive motor fields are actuated by two tuned circuits resonated at 55 and 65 cycles. The lower frequency coil is wound opposed to increase the speed of the motor. The 65 cycle coil is wound aiding to increase the DC field current. The reaction of the two currents maintain a constant 60 cycle output.

Figure 7(b) shows the device applied externally to transformer regulation. The component X across coil #1 indicates a non linear device, (VR tube, Thyrite Etc.) used as a combined reference voltage across coil #1, and a current amplifier for coil #2. Two element non-linear devices are shown for simplicity. When a-c is used as a voltage reference, a small saturable reactor is used for a non-linear device—usually in a bridge connection.

Control coils 1 and 2 may also be applied to choke (L) which would effectively transfer the filter condenser

## VOLTAGE REGULATORS




**MOTOR-GENERATOR. Voltage & frequency regulated by magnetic amplifier.**

**Fig. 7(a)**

(C) to the other side of the choke upon saturation. The condenser input effect would result in good plate voltage regulation, with Fil. unregulated.

Figure 7(c) shows a regulator designed integral with the equipment transformer. This system is used in a special 440 cycle type of aviation radar equipment, and for portable installations where light weight is desired. Insert shows the core arrangement. The above circuits are shown to demonstrate the theory of operation. Other circuits may have superior operating characteristics.

The significance of constant voltage is appreciated when it is realized that an estimated 80% of all electronic failures can be directly traced to tube or condenser failures—this does not include transformer, choke and resistance failures which can usually be traced to overloads occurring during these failures.

ELECTRONICS POWER SUPPLY REGULATORS

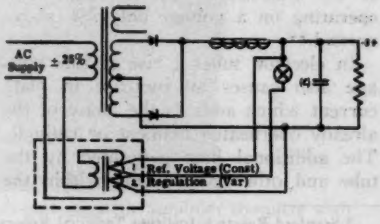



Fig. 7(b)

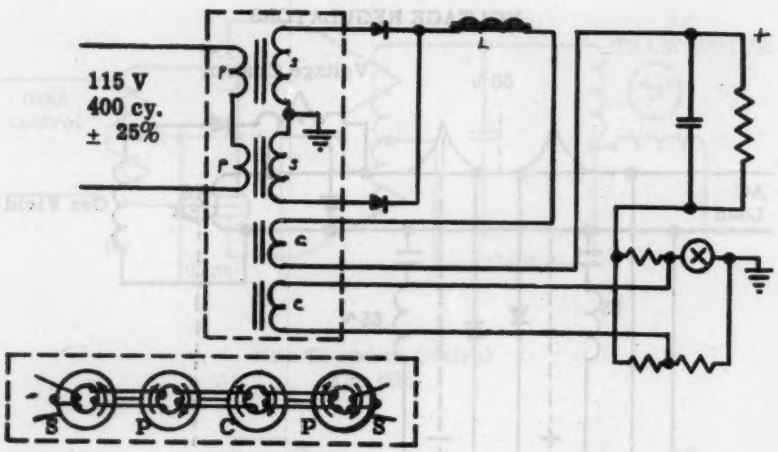



**Fig. 7(c)**

"Tubes are listed as the greatest single cause of electronics failures. Cathodes or filaments have an optimum temperature of operation. The incident of failure rises rapidly as temperature is exceeded. Not much data exists on the effect of under temperature operation. It is known that although the latter condition is not as serious as the other, it does shorten tube life. It is desirable to run the heaters at normal ratings from regulated power supplies when long stable service is required of tubes." * Life tests on tubes operated on above normal voltages are not available; however, life tests on incandescent electric lights show that the life of the filament is reduced 50% when operating on a voltage only 7% above normal.**

In electron tubes a rise in line voltage also causes an increase in plate current which adds to the abuse of the already overheated filament or cathode. The additional heat generated by the tube and other components within the equipment compartment cause the ambient temperature to rise which also contributes somewhat towards accelerated equipment failures.

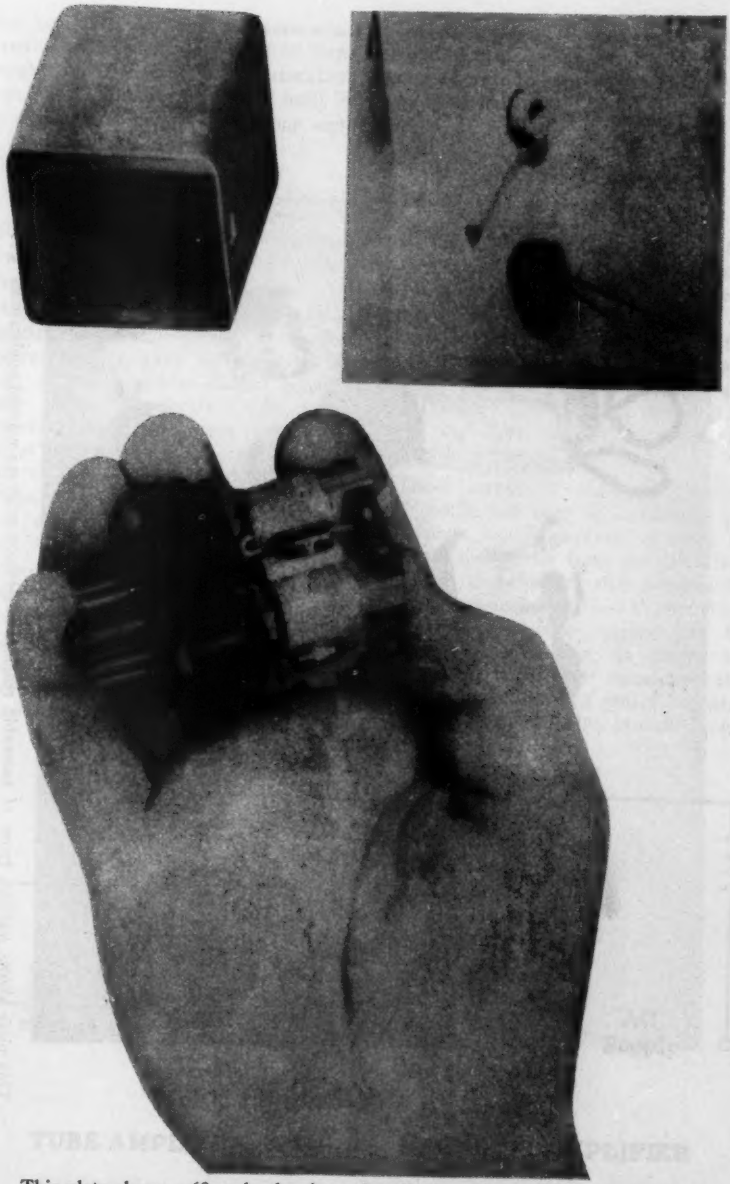
Another point often overlooked is that once the tubes have been operated under accelerated conditions their performance is considerably reduced when returned to normal operating voltages.

Military equipment is designed to operate at ± 10% of a specified voltage. The service free life however is reduced considerably when operating in the upper voltage range.

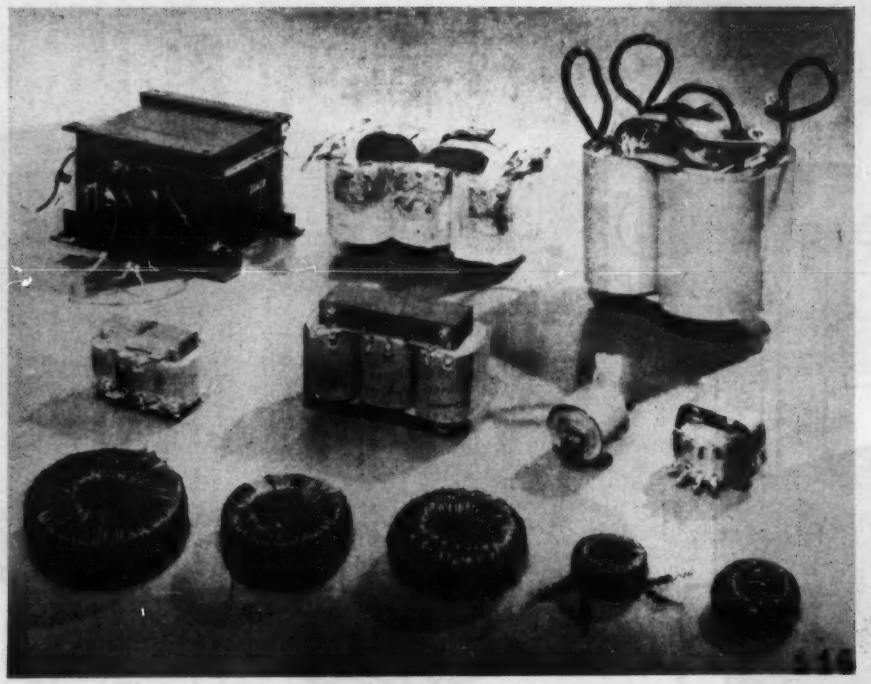
Normally the larger naval vessels have excellent voltage regulation. This voltage however is maintained to the trunk lines; the branch lines due to intermittent loads are difficult to regulate. This results in accumulated equipment strains, eventually ending in complete failure.

Several manufacturers can supply automatic voltage regulators as components to be inserted between the line and equipment. These are rather large,

* Stanford Research Institute Terminal Report—1 June 1950
** Chapter 2 NAVSHIPS—250-660



This plate shows a 60 cycle plug-in push-pull magnetic amplifier complete with rectifiers. 0.0IV/A (GE.Co.). Insert compares 1.5 MC Coil size to Pencil (ERA St. Paul).



This plate shows various types of saturable reactors used for machinery control applications (Vickers Inc.)

with low efficiency and are somewhat sensitive to frequency, as most of them operate on the resonance saturation principle. Regulators should be built in the power transformer rather than supplied as a separate component. They should be made mandatory for all equipment where interruptions due to failure may be serious.

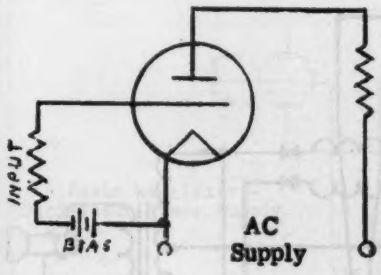
## Audio Frequency Amplifiers

From an electronics angle, perhaps an analogy between a tube and a magnetic amplifier should be made.

Any attempt to analyze the magnetic amplifier in direct relation to a tube requires that certain assumptions be made, as this amplifier differs considerably from the electron tube type. However, since the input saturation control voltage vs. load current can be made to follow almost precisely that of a tube, a theoretical analysis can be made on the straight portion of the curve.

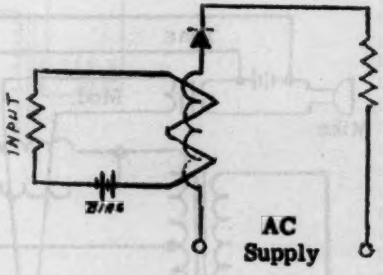
Figures 8(a) and (b) are sketches of a tube and magnetic amplifier; (c) is a magnetic saturation vs. impedance curve of a typical magnetic amplifier. Since this curve almost duplicates that of certain type tubes, operating characteristics of both can be plotted on the same curve. For a fair comparison the "Plate" supply of both amplifiers must be AC, as a magnetic amplifier will not control DC. If this amplifier is to be used to amplify audio frequencies the supply frequency should be above audibility. Since both amplifiers are single ended, they must be operated as class "A," half way up the slope, as shown in curve (c), point (a).

These amplifiers working as class "A" would not only be inefficient, but provisions would have to be made to separate the carrier from the voice frequencies; consequently they are usually operated as push pull class A/B. With this connection the carrier can be point (b) biased out, as shown by Fig. 8(d). With P/P connection the "plate" supply rectified pulses are also doubled and practically cancelled out.



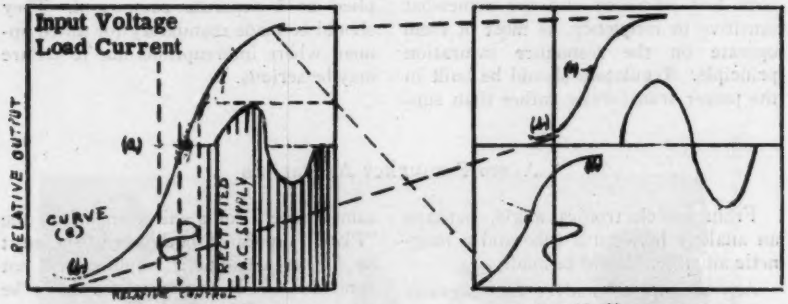

TUBE AMPLIFIER

Fig. 8(a)




MAGNETIC AMPLIFIER

Fig. 8(b)




CLASS "A" SINGLE
Fig. 8(c)

CLASS "B" PUSH PULL
Fig. 8(d)

Figures 9(a) and 9(b) show basic sketches of more practical push pull amplifiers. These amplifiers have been built with power outputs up to 500 watts, with excellent linearcy up to 7000 cycles.

According to two British investigagators (Williams/Noble—IEE, 50—See Bib.), it is possible to amplify control signals of ten to the minus 18 watts at a bandwidth of 10 cps in a special magnetic amplifier having a basic limitation of 4 x 10 to the minus 20 watt due to thermal noise. Barkhausen effects in the same magnetic amplifier are equivalent to a signal input of 10 to the minus 19 watts for a bandwidth of 1 cps. Drift is the major limiting factor in low input applications.

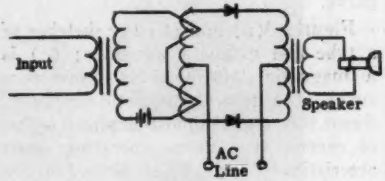



Fig. 9(a)

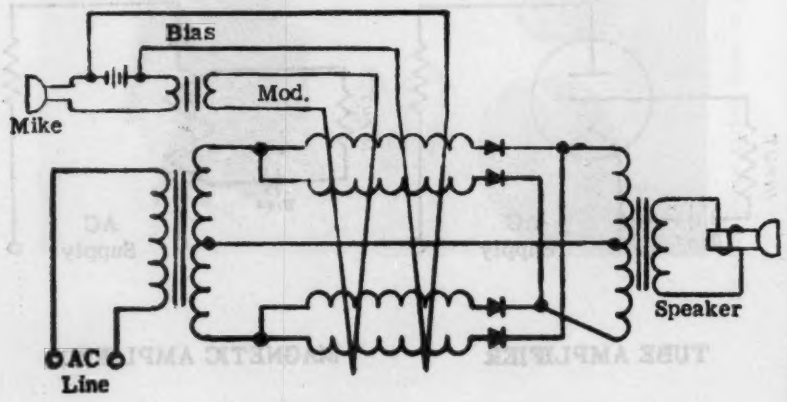
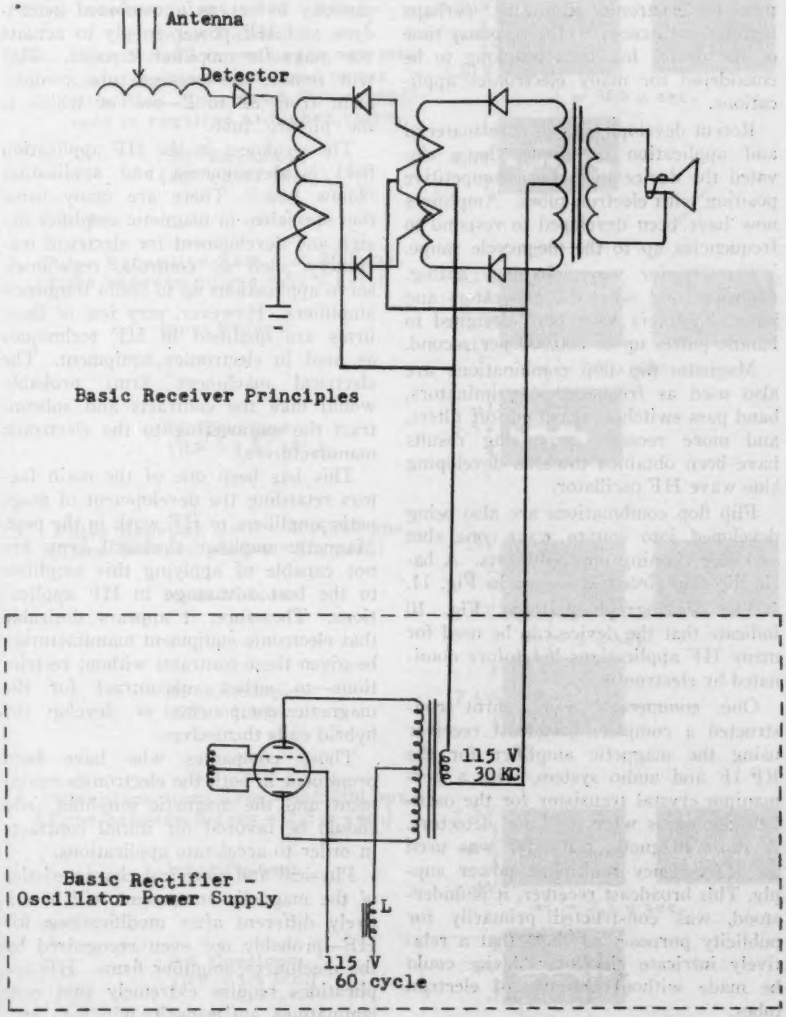



Fig. 9(b)


Antenna
Detector
Basic Receiver Principles
115 V
30 KC
Basic Rectifier -
Oscillator Power Supply
L
115 V
60 cycle

Magnetic Amplifiers are relatively new to electronic engineers, perhaps because until recently, the response time of the device has been too long to be considered for many electronics applications.

Recent developments in core material and application techniques have elevated the device to a more competitive position with electron tubes. Amplifiers now have been developed to respond to frequencies up to the megacycle range.

Circuits for wave shaping, gating, counting, and for pulse generators and pulse amplifiers have been designed to handle pulses up to 500,000 per second.

Magnetic flip flop combinations are also used as frequency discriminators, band pass switches, sharp cut-off filters, and more recently promising results have been obtained towards developing sine wave HF oscillator.

Flip flop combinations are also being developed into square wave, one shot and free running multivibrators. A basic flip flop circuit is shown in Fig. 11.

The oscillograph patterns, Fig. 10 indicate that the device can be used for many HF applications heretofore dominated by electron tubes.

One commercial radio firm constructed a complete broadcast receiver using the magnetic amplifier for the RF-IF and audio system, with a germanium crystal transistor for the oscillator; crystals were used for detectors. A static magnetic converter was used as a frequency multiplier power supply. This broadcast receiver, it is understood, was constructed primarily for publicity purposes to show that a relatively intricate electronic device could be made without the use of electron tubes.

Aviation interests are now considering placing contracts on a loran receiver-indicator completely actuated by magnetic amplifiers except for the scope and oscillator tube. It is planned to design the oscillator with sufficient capacity to act as a combined heterodyne and HF power supply to actuate the magnetic amplifier circuits. This will reduce the present tube complement from 32 to 2—one of which is the "picture" tube.

The weakness in the HF application field is development and application "know how." There are many firms that specialize in magnetic amplifier design and development for electrical machinery such as controls, regulators, servo applications up to audio frequency amplifiers. However, very few of these firms are qualified in HF techniques as used in electronics equipment. The electrical machinery firms probably would take the contracts and subcontract the engineering to the electronic manufacturers.

This has been one of the main factors retarding the development of magnetic amplifiers to HF work in the past. Magnetic amplifier electrical firms are not capable of applying this amplifier to the best advantage in HF applications. Therefore, it appears desirable that electronic equipment manufacturers be given these contracts without restrictions—to either subcontract for the magnetic components or develop the hybrid coils themselves.

Those companies who have been prominent in both the electronics equipment and the magnetic amplifier field should be favored for initial contracts in order to accelerate applications.

Physical and electrical characteristics of the magnetic component will be entirely different after modifications for HF—probably not even recognized by the machinery amplifier firms. HF applications require extremely thin core laminations, anti-capacity windings, etc., that are not found in present production units.

Following are some of the core characteristics desirable for HF applications.

1. Pulse Repetition Rate = 2000 pps.
(Time between pulses = 500 u sec.)

Input Pulses:

Note: Input Pulses in each case are minimum amplitude required to set Flip Flop. Increased Pulse amplitude is required at higher rates.

RF Envelope:
(RF = 1.42 Mc.)

2. Pulse Repetition Rate = 20,000 pps.
(Time between pulses = 50 u sec.)

Input Pulses:

RF Envelope:
(RF = 1.32 Mc.)

3. Pulse Repetion Rate = 200,000 pps.
(Time between pulses = 5 u sec.)

Input Pulses:

RF Envelope:
(RF - 1.4 Mc.)

4. Pulse Repetition Rate = 400,000 pps.
(Time between pulses = 2.5 u sec.)

Input Pulses:

RF Envelope:
(RF = 1.5 Mc.)

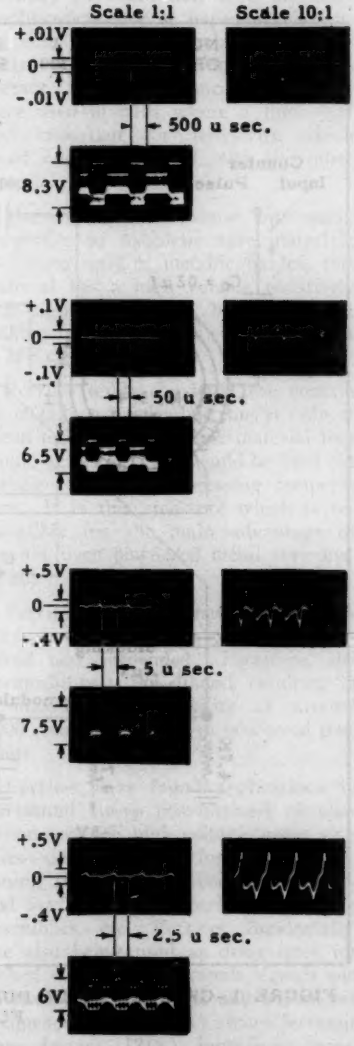



FIGURE 10 - MAGNETIC FLIP FLOPS DRIVEN AT HIGH RATES

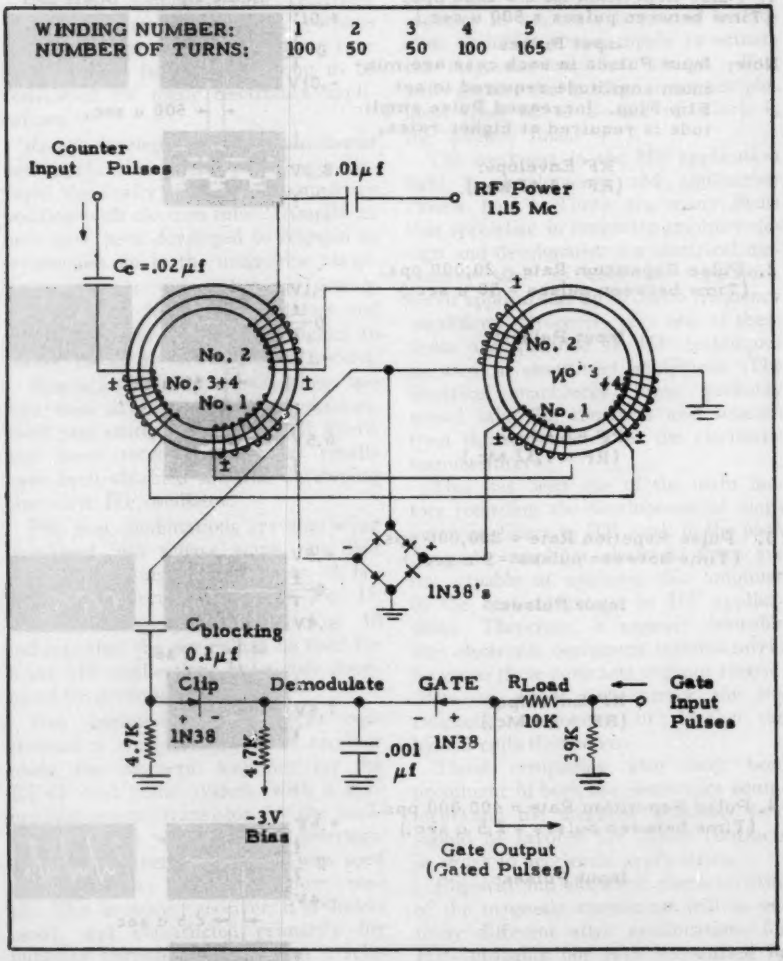



FIGURE 11 - CRYSTAL DIODE PULSE GATE CONTROLLED BY MAGNETIC FLIP FLOP

1. The core must be easily saturable.
2. Eddy current effects must be at a minimum.
3. Hysteresis losses must be low.
4. The physical mass of the core must be small.
5. The effective retentivity of the core must be low.

The oscillograph patterns of Fig. 10 were made from the output of Fig. 11 which contained a core made of 4-79 molybdenum permalloy tape ⅛ mil thick and 3/32 inch wide. The core had an inside diameter of ¼ inch and weighed 20 milligrams; the ratio of inductance from zero to maximum saturation was 4:1—(80 to 20 uh). The RF anode power supply consisted of a single tube oscillator supplying each magnetic stage with about 20 MA at 20 volts. The excitation voltage of course varied with signal input.

The above information together with the oscillograph pattern Fig. 10 and Fig. 11 was obtained from a BuShips contract report as furnished by Engineering Research Associates, Inc., St. Paul, on saturable-core reactors as digital computer elements. This contract was completed 17 June 1949.

This research indicates that conventional rolled core material can be used for frequencies up to possibly a megacycle with fair efficiency. Beyond this range preliminary investigations indicate that composite iron or related magnetic material such as powdered iron or ferrites may be superior.

Powdered iron cores similar to those used in conventional RF tube circuitry are not suitable for efficient magnetic amplification.

In powdered iron cores, the desirable high volume resistivity is achieved by bonding fine metal particles in some form of organic binder. This reduces the permeability and leaves the core full of air gaps which is undesirable from the standpoint of efficient saturation required for magnetic amplifiers.

The deficiencies of the powdered iron core, however, can be ignored in certain circuitry in connection with magnetic amplification such as impedance matching coils and other specialized applications where amplification is less important. In one instance these cores were used in coils where a high "Q" was important for selectivity which could not be achieved with the other material.

Magnetic ferrites show interesting properties as magnetic core material; consisting only of metallic oxides, this material has a high volume resistivity and high permeability, but low losses, making for reduction in size and weight in HF circuitry.

Ferrites, unlike powdered iron, contain no metallic particles but consist only of metal oxides; any organic material that would act as air gaps would be fired out during the 2300° processing temperature. It is this structure which is responsible for the main advantage of ferrites over powdered metal core materials in HF circuits.

Ferrites, with their natural high specific resistance do not have to be powdered and suspended. Therefore, the permeability is not diluted, resulting in a maximum permeability of around 1000 compared to 100 in powdered iron rings.

Ferrites have found applications in horizontal sweep transformers of television sets, RF high voltage power supplies—deflection yokes for TV receivers, tuning stugs for RF coils, core material for FM oscillators, high "Q" core assemblies, etc. Ferrites, incidentally, are also being used as delay lines for pulsed video and supersonic signals and as transducers at sonic and supersonic frequencies. Fig. 12(a) shows ferramic core forms; 12(b) hysteresis loops. 12(c) shows a comparison between a magnetic and a tube amplifier—these are single stage RF computer components designed by Transducer Corp.

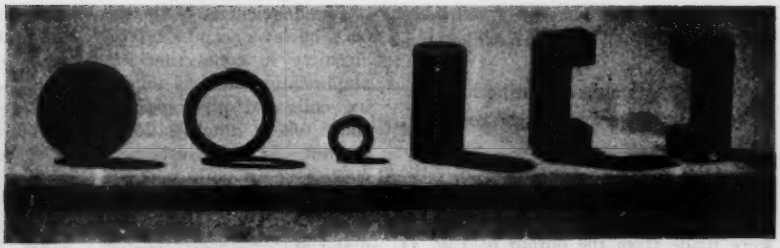


Fig. 12 (a) - Ferramic parts in the form of a disk, toroids, slug and C-shaped transformer cores were pressed. The rod, which is 20 in. long and 3/8 in. diam, was extruded. A spiral inductor was printed directly onto the ferrite disk, illustrating the high specific resistance of this material.

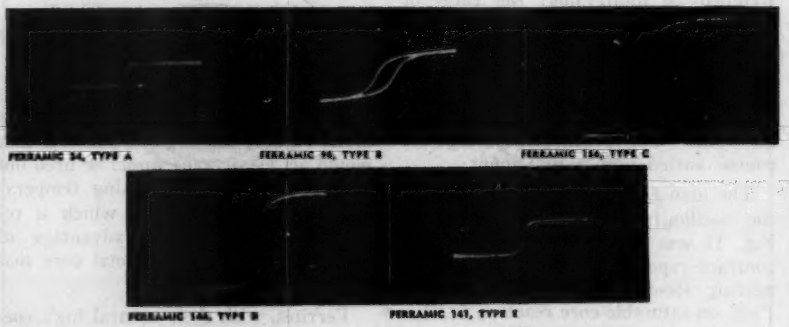



Fig. 12 (b) - Oscillogram traces of hysteresis loops of five types of ferrites.

Very little definite information has been obtained on special HF core material—whether ferrites or some other composition is best suited for high frequency magnetic amplifier cores has not been determined.

Most of the above material on ferrites was furnished by General Ceramics & Steatite Corp. which was supported in part by U. S. Signal Corps.

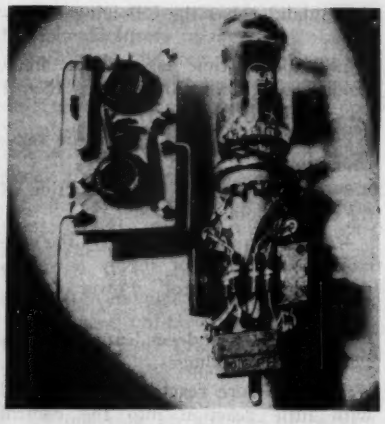
If sufficient emphasis is put on these applications of the magnetic amplifier the program need not be a long term one. The prospects of much greater reliability and simplification of electronic equipment which appear to be immediately available should not be ignored.

In addition, recent developments in transistors and dielectric amplifiers offer possibilities of using a combination of all three devices to eliminate all tubes except those used for visual displays.

## Addenda (Electronics)

Since very little data was available on the relative merits of ferrites over steel cores when used as amplifiers at high frequencies, Mr. Miles of Engineering Research Associates kindly consented to make an exploratory test.

Figure 12d is an oscillogram, showing relative response of both materials



Virtually trouble-proof magnetic binaries (left) designed by Transducer Corporation can replace up to 90 per cent of the delicate vacuum tubes (right) in certain digital computers.

Fig. 12(a)

at 2 Mc. The patterns are self-explanatory.

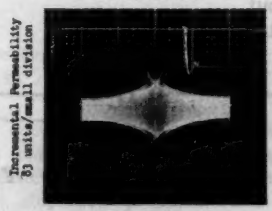
The relationship of 'effective incremental permeability' to control (or bias) mmf is pertinent to the design of magnetic amplifiers. ( Effective incremental permeability is defined as that ratio $\Delta B/\Delta H$ achieved at the specified operating frequency at which $\Delta H$ is cyclically varied, the alternating magnetic field operating in conjunction with a specified constant biasing field to cause an alternating magnetic induction, $\Delta B$). The accompanying 'butterfly' curves display such data for identical excitation conditions where the excitation ($\Delta H$) frequency is 2 Mc.

It is desirable, for sensitive magnetic amplifiers, that a maximum change in effective incremental permeability be achievable in response to a minute change in control mmf. Therefore, the core having the maximum absolute slope in its butterfly characteristics will be best for use in such a magnetic amplifier. By observation of the accompanying butterfly curves, and by taking into account the scale-factors, the relative merits of the two described cores may be observed. It will be seen that, at 2 Mc, the ⅛ mil thick metallic ribbon core (Moly-Permalloy) is radically superior to the ferrite core (Ferroxcube HiMu IV-B) when judged according to the above stated criterion.

This is, however, not necessarily conclusive as ferrites can be mixed, treated, or even grown as a single crystal, for specific reactions. The ferrite core used in this test was a representative production type designed for universal applications.

COMPARATIVE EFFECTIVE INCREMENTAL PERMEABILITY DATA FOR SUPERIATIVE HIGH-FREQUENCY CORES*
(Manufactured 1950-1951)

ARMCO MOLYBDENUM-PERMALLOY CORE
1/8 mil thick laminations
2 Mc excitation




BIAS MMF
0.17 Oersteds/small division

FERROXCUBE HI-MU IV-B CORE
2 Mc excitation

BIAS MMF
0.17 Oersteds/small division

* Note different scale factors on the two oscillograms.

Fig. 12(d)

Figure 13 shows a basic sketch of a rather interesting M/A development recently disclosed by Dr. Robert A. Ramey of Naval Research Lab.

This approach to the M/A problem has resulted from the recognition that the amplifier is a voltage sensitive device, and not as generally believed a current sensitive device. The only truly independent variable is the control voltage.

The remarkable fact that the time of response of this series amplifier does not depend upon the inductance of the transformers as reactors seems to be adequately shown by analysis.

A preliminary review indicates that this amplifier has the following advantages.

1. Response time is constant, independent of gain. (Always less than 1 cycle of supply frequency.)

2. Lighter and smaller for the same power output.

3. The output is a linear function of the control voltage.

4. Greater power sensitivity; the control source need not supply power to the amplifier control. Power is absorbed instead.

5. Relatively independent of variations in supply voltages.

6. Single core reactors may be used with little reaction into the control winding.

**NEW DEVELOPMENT**

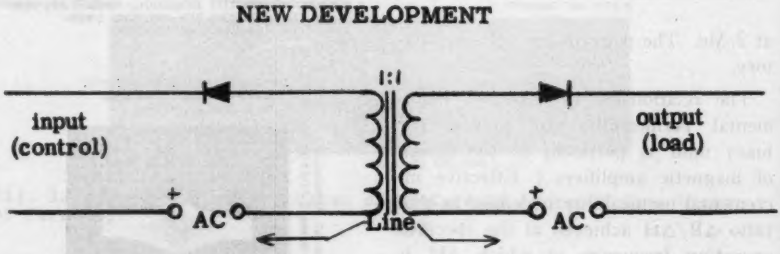



**Fig. 13**

Note: This circuit has not as yet been evaluated by BuShips Engineers.

GENERAL COMMENTS

The emphasis on magnetic amplifiers should be directed towards definite applications in electronic equipment to increase *reliability* where this can be accomplished without an overall reduction in operational performance.

The unreliability of current electronic equipment is a very serious problem and evidence exists that the electron tube is the largest single factor in equipment failures. The following quotations are of interest regarding the reliability of electronic equipment, in particular the electron tube.

"For military services two factors are of extreme importance. (1) an overwhelming problem of equipment maintenance; and (2) an almost insuper-

able demand on production facilities of the manufacturers in the event of total mobilization, making replacement of components and (or) equipment due to failures a serious problem. Any preventative measures taken now will result in high dividends during an emergency and for years to come." *

"The developing complexity of electronic circuits, such as radars and sonars, make the tube problem a serious one. Data gathered for this study indicate that in equipments using components which meet military specifications or best commercial grades, the electron tube accounts for more than 50% of circuit failures.

"In one case an analysis on service calls over an eight week period showed that 72% of the breakdowns were due to tube failures.

"In Commercial Aircraft electronic equipment it is reported that 70% of equipment failures are due to tube faults, even though the tubes are ruggedized units whose average life has been improved by a factor of more than 24 over the standard commercial types.

"With an increasing number of tubes used, and greater reliability of other components, the reliability of the equipment becomes more and more the reliability of the electron tube itself." **

The application of magnetic amplifiers to RF and other high speed wave forming circuitry are not considered as feasible of accomplishment within the immediate future. These applications will require long range developments.

The applications based on the uses outlined in this article have had considerable development both in this country and abroad and therefore should be considered first for specjal applications.

* ONR Monthly Research Report 1/50
** Stanford Research Inst. Terminal Report 11/50

## MAGNETIC AMPLIFIERS
## APPLICATIONS

(The following list of magnetic amplifier applications was originally submitted as an enclosure to a Bureau of Ships, Electronic Design & Development memorandum dated 11 October 1950.)

"Applications of the Magnetic Amplifier" are listed as follows:

a. AMPLIFIERS—AC or DC for current voltage and power. Example: Low level DC applications: Thermocouple and photocell amplifier to directly operate motors and controllers. Amplification gains of several million can be realized without the use of electronic tubes but with rather long time constants. This is an excellent DC Amplifier. This amplifier is not subject to drift difficulties often encountered in electron tube installations.

b. REGULATORS—(most common use) control of voltage, current and frequency of industrial power installations, ship main propulsion and auxiliary units, aircraft automotive electrical equipment, line to line voltage regulators independent of frequency. (Regulating applications have been thoroughly proven and should be considered for all auxiliary generators supplying power to electronic equipment—a large portion of electronic equipment failure can be attributed to poorly regulated power supplies.)

c. RELAYS—Locking including normally closed, open or frequency sensitive relays. (The substitution of these units for mechanical relays should be considered for equipment used in the tropics, where contact and mechanical

difficulties are encountered due to humidity and fungus, as they contain no contacts and moving parts and can be completely sealed.)

d. SATURABLE REACTOR—Lighting control, variable impedance, etc. Single units are currently used to control up to 50,000 KVA.

e. MOTOR STARTERS, ELECTRICAL WELDING AND AUTOMATIC BATTERY CHARGING CONTROL—The effectiveness and sensitivity of regulating controls are considerably increased by the addition of a non-linear device such as a THYRITE or glow tube which can be connected to effectively amplify the error or act as a reference source themselves.

f. CURRENT LIMITING REACTORS—Limiting power currents during short circuits. Limiting armature currents during slow motion or static conditions in follow-up motors.

g. SERVO SYSTEMS—Complete, utilizing magnetic amplifiers as regulators, converters, computers, and as a complete replacement for thyration and a rotary magnetic amplifier (amplidyne) system, at less cost and weight.

h. INSTRUMENT AMPLIFIERS—Remote control, etc.

i. SYNCHRONIZER—For automatic pulse and frequency control.

j. DIFFERENTIATING SYSTEMS—for course plotters and predictors. (Example: Direct integration from DECCA, RAYDIST LORAC and RADUK-II phase comparison meters to graphic course plotters) constant speed controls for Surveying, Wire Drag, Mine Laying, Convoys, etc.

k. AUTOMATIC STABILIZERS & PILOTS—For submarine and aircraft. (AC power supply systems for aircrafts are well established making saturable reactor control extremely attractive.)

l. IMPULSE STORING AND MEMORY DEVICES.

m. TIMERS—Timing pulse generator for radar and loran equipment—Wave shaping, etc. (currently produced with frequency range between 25 cycles and 1 MC.).

n. ELECTRICAL COMPUTERS—Add—subtract—multiply—divide—differentiate—or integrate electrical quantities.

o. CONVERTERS—DC to AC—AC to DC.—Another method of converting DC to AC at both 60 and 400 cycles for the electronic equipment on auxiliary vessels equipped with DC main generators. Rotary converters and motor generators on any vessel have always been a maintenance problem. This application is still under development.

p. OSCILLATORS—Within limited frequency range.

q. PHASE SHIFTERS—Reactance control to ¼ cycle—currently used as phase shifters in grid control of mercury arc rectifiers—and pulse delay matching circuits in radar equipment.

r. FUEL PUMP REACTOR DRIVES—(In location where relay starting and controls contacts sparks could cause an explosion).

s. MODULATORS—Voice frequency modulators and RF carrier trigger circuits. Frequency shift keyers, etc.

t. FREQUENCY MULTIPLIERS AND REDUCERS—Including telephone tone and ringing circuits up to RF. In one type of frequency multiplier a direct current flux is added to cause operation of the unit at the most efficient point for the generation of the desired harmonic. Another static type recently developed to convert 60 cycles to 420 has an efficiency of 60% with a considerable reduction in weight over comparable rotating equipment.

u. SEISMOGRAPH AND MAGNETOMETER AMPLIFIERS—tide gauge, anticipator, audio gain sequence circuits.—Drift difficulties often encountered in these applications are usually reduced when this device is substituted for tube amplifiers.

v. MULTIVIBRATORS—One shot and free running square wave generators.

w. SWEEP GENERATOR—Trigger and pulse forming circuits for Radar and Loran equipment.

x. COUNTER AND DIVIDERS—For loran, shoran and radar indicators.

y. MINE AND SUBMARINE DETECTORS.

z. FIELD CONTROL FOR MAGNETIC FLUID CLUTCHES AND MAGNETIC POWDER BRAKES—One manufacturer has replaced the regular DC charging generator on an experimental bus with a 400 cycle AC unit. The generator voltage is magnetic amplifier controlled to plus or minus 2% from idling to full speed. Magnetic amplifiers are then used to obtain optimum battery charging rates, and as remote controls for the powdered iron brakes, clutch and miscellaneous auxiliary equipment, including RF ignition systems.

## ADVANTAGES

The Magnetic Amplifier has several advantages for electronics which are as follows:

a. They contain no moving parts. Maintenance of the unit without rectifiers is comparable to that of a conventional transformer. With rectifiers the life is governed by the type of rectifiers used—conventional radar germanium crystal rectifiers are used in the low powered units—dry disc in the larger units. These rectifiers are conservatively rated at 60,000 hours for full power operation.

b. RUGGEDNESS — Shock resistance equivalent to that of a transformer of similar size.

c. STABILITY—Less affected by variations in power supply voltage fluctuations in that there is no cathode emission change with filament temperature, (in low input and HF applications constant anode voltages are important). Unbalanced effects in balanced circuits due to cathode emission changes are practically eliminated because of the inherent stability of a rectifier compared to a hot cathode.

d. OVERLOADING — A Magnetic Amplifier can carry overloads equal to an equivalent transformer.

e. ENVIRONMENTAL — Can be hermetically sealed and inconspicuously built in as part of the equipment. Normally requires no ventilation and can be installed in compartments with combustible material.

f. HIGH GAIN — Power gain per stage is comparable to that of a vacuum tube stage. They can be cascaded almost to any power gain. The efficiency is also greater.

g. CIRCUIT ISOLATION — The inputs and outputs are electrically isolated.

h. SAFETY — Can be safely operated in enclosed areas where starting relays and control contact sparks could cause an explosion.

i. ADAPTABILITY—These amplifiers can be built with special shaped cores for mosaic installations in confined spaces. Amplifier gains can be changed simply by adjusting the DC fields. Gain control leads are less affected by stray RF pickup noises often encountered with high resistance high voltage components necessary in equivalent electron tube circuits. Separate low impedance gain windings may be added to the core if isolation is required; (permanent magnets with adjustable air gaps, may in certain applications be used to set fixed gain). Separate windings may also be used to introduce feed back, either positive or negative to obtain increased amplification or degeneration to improve the

frequency response. In addition to the above, separate windings have been added to superimpose independently varying signals in either phase relation or amplitude or both for specific purposes.

j. These amplifiers are also excellent devices to use in conjunction with electron tubes for many applications. Tube controlled core saturation can be applied to many existing electron tube installations with a resultant increase in stability operating range and overload protection.

k. READINESS—They require no warm-up time. Example—Gun control units would not have to be kept continuously energized for instant use.

DISADVANTAGES

Although this amplifier has advantages as given in paragraph 2 it also has disadvantages and these are listed below:

a. TIME CONSTANT—In general, the time constant is long compared to that of vacuum tubes and short compared to electro-mechanical devices. Current servo production units have a lag of one cycle of exciting frequency. Pulse trigger circuits are being designed with lags of less than one microsecond with a HF Power source. Actually, it may be possible with modern materials and techniques to obtain time constants in most cases, comparable with those of vacuum tube circuits, especially in similar applications.

b. IMPEDANCE RANGE — The impedance of a Magnetic Amplifier cannot be increased to infinity or decreased to zero—reflected impedances, therefore, must be considered. With full output (core saturated) the output impedance is reduced almost to the DC resistance of the core windings and (if used) rectifiers. Inputs may be designed with an impedance of a fraction of an ohm to a megohm or more.

c. AGING—If feedback units requiring rectifiers are used the life of the rectifier is the age determining factor. Modern dry type rectifiers, conservatively operated have a life expectancy many times that of a vacuum tube, and will stand considerably greater overload surges, and should not, once installed, require service or maintenance during a service life of at least five years. The log book of the German cruiser *Prinz Eugen* shows that not one of the various types of Magnetic Amplifier used on that vessel for gun stabilizers and servos, required servicing for a period of ten years).

d. FREQUENCY LIMIT—The upper frequency limit of a magnetic amplifier appears at the present stage of development to be about a half million cycles. It is assumed, without further investigation, that this limit occurs due to eddy currents within the core, or winding capacity effects or both. Response of pulse repetition rates up to 400,000 per second have been obtained with time constants of one microsecond, using 3 Mc as excitation frequency.

e. CAPACITY—The capacity of the series saturated amplifiers currently produced are limited to around 10 kilowatt due to the size of the rectifiers. Shunt compound units have been built with capacities up to 50,000 KW. Theoretically there is no upper limit to power handling capacity of these amplifiers, likewise there is practically no lower limit; magnetic amplifiers are capable of amplifying signals too weak to penetrate the emission shot noises of a vacuum tube.

f. SIZE—In many low powered applications the magnetic amplifier may be larger and heavier than competitive units. This is especially true in the 60 cycle components—the size of the core is almost inversely related to frequency. For a given size the 400 cycle

amplifiers would have about five times the capacity of its 60 cycle counterpart. The linearity and response time is also improved almost directly in proportion to frequency. High speed replacement units for vacuum tubes, however, indicate that they may be much smaller and lighter than equivalent vacuum tube circuits.

COST—Initially, until mass production is established, these amplifiers will be more expensive than the components they replace. This is due not only to the necessity of absorbing part of the research cost in the first production units, but also to allow protection to cover any possible engineering problems that may develop in special applications. Indications are that once mass production is established magnetic amplifiers can compete in cost not only with electron tube components but with the cheaper electromechanical devices as well.

## CONCLUSION

The uses indicated in the above list are but a few of the many applications. Not all of the magnetic amplifier applications mentioned are commercially available, as some are still in the experimental stage. Basic research on magneto-strictive magnetic amplifiers, oscillators and power units utilizing composite cores of nickel, iron, cobalt, in bridge circuits with permanent magnets for fractional saturation bias levels are now being studied for special applications.

Magnetic amplifiers should not be considered as a substitute for all tubes and relays in control and regulating circuits. Each application should be weighed and balanced against competitive installations. In certain installations, these amplifiers may actually be larger, heavier and less suited than other means. A magnetic amplifier should be considered only if its advantages outweigh its disadvantages when compared with competitive means.

Magnetic amplifiers should be considered for applications within their limitations for many types of equipments now using vacuum tubes, relays, rheostats, circuit breakers, meters, certain rotating devices, self-synchronous transmitters, receivers, etc. The reduction of vacuum tubes alone, by any device, is a consideration, when it is realized that the electronic equipment on a single battleship today requires over 7500 tubes, and the number is rapidly increasing. Aircraft Carriers require up to 13,000 tubes excluding equipment installed in planes and in specialized computers. Storage space requirements for three times this number of spares is also a consideration.

The substitution of magnetic amplifiers for all mechanical regulating devices used on auxiliary power units supplying electronics equipment should be made mandatory, limited only to availability. These are relatively simple applications, and should be the first to be considered.

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# PART TWO

## REPRINTED ARTICLES

The articles contained in this Part Two represent those which, in the opinion of the editorial staff, are the most valuable which have been gleaned from recent issues of contemporary publications.

This material was formerly published under the heading "NOTES". It has been given somewhat more prominence and made more readable to enhance its value. The editors' purpose here is to provide a convenient repository to readers of the JOURNAL, for articles originally published elsewhere which contribute to the purpose of the Society: to further the advancement of naval engineering.

# SHIPYARDS—BIGGEST WEAKNESS IN OUR WAR POTENTIAL?

ACKNOWLEDGMENT

ASHLEY HALSEY, JR., on the staff of "The Saturday Evening Post," is the author of this article, which appeared in the "U. S. Naval Institute Proceedings," July, 1951. The article presents a strong case for an expanded shipbuilding program in this country.

This is a story that can be told in many ways and should be told often. It can be told in terms of Joe the welder who lost his job, Joe the seaman second or G.I., and Joe in the Kremlin smiling behind his heavy mustache. It can be told in dry statistics on keels laid, construction completed or canceled, gross tonnage, displacement tonnage—or in the uncounted moments of a man struggling in a lonely sea to hold to a liferaft slippery with oil, and another man on a far distant hillside fingering his last handful of cartridges and wondering how soon the next enemy rush will come.

It is a story of some ships built in time, some ships built too late to serve their intended purpose, and some never built at all; of 1,200,000 shipyard workers who helped to win the biggest war in history and in doing so helped themselves out of jobs and onto the sidewalks; of popular economies and shortsighted policies that cause a great nation to grow fat at the waist and at the same time short of reach when it has to punch back.

It is anything but a happy story, and it may be very sad indeed for thousands like the man struggling with the liferaft or the man on the hillside counting his cartridges. On every field where fighting men are forced to wait for aid from overseas, it may mean a desperation that is blood kin to Bataan and its bitter downfall, to Guadalcanal with its heavy nearness of defeat, and to Korea with its painful reverses. At home it is the story of our private shipyards—how they have become the Forgotten Industry in our national defense setup and whether we have remembered them in time.

## LOGISTICS—MORE TONNAGE OVER MORE THOUSANDS OF MILES?

Not even the best military brains in the world can predict the course of a war with assurance. The unexpected is one of the things that makes warfare so costly; either you spend prodigiously to be prepared on many fronts in many ways or you gamble on being ready only on a limited basis and accept your risks accordingly. The American way throughout most of the nation's military history has been to gamble heavily. Time and again, the nation's gambling debts have been paid in lives instead of dollars.

Both in human risks and in cold cash, war never has been costlier than it is

today. Never have civilian populations been so endangered. Never has there been so much for the defense dollar to buy, or so many places to spend it. The rows of billion-dollar figures lose all meaning to the average American except to make him feel that we are spending fabulously and should be getting everything that the national defense requires. The Korean conflict quickly brought an awareness that much of our expenditure and effort up to that point went for pilot models, piecemeal material replacement, and the development of capacity to produce new weapons rather than for stockpiling such weapons. Yet there remains a feeling that we shall measure up adequately in armaments before long. Granted that such a comforting situation may come to pass, it still carries us only to our own water's edge in a global war.

An allout war that flames in many places at once can confront the logistics planners with the most nightmarish shipping problems imaginable. Unless hostilities come on the installment plan —a small invasion here, a minor aggression there—the transportation problems of a global war may resemble those of World War II much multiplied in volume. Routes and distances will be much the same as in 1942-45: Some 3500 miles across the Atlantic, nearly twice that to Japan and the Far East, and along whatever route is open to Iran and the rumbling under-belly of Asia. The similarity ends, however, when one turns from charts and routes to loading tables and cargo tonnage.

As American forces closed in around Japan in the recent war, this country found itself shipping more than 600,000 tons of war material a month into the Pacific. In the shore bombardment and sea operations around Okinawa alone, the Navy fired 50,000 tons of five-inch to sixteen-inch ammunition. Impressive though these figures are, they appear to be as obsolete as a muzzle-loader in the light of present-day needs. A recently published estimate places the amount of shipping necessary to transport a single armored division—men, tanks, and other gear, and supplies for an unstated but probably brief period—at 250,000 tons. The estimate was based on tanks of models now in use. If the Armored Forces' experience with Russian-made tanks in Korea means anything, American tanks will be larger and heavier in the near future. Their guns, and most other field and air armaments, will be larger and will fire a greater weight of projectiles at a faster rate, making munitions tonnages soar.

In the event of fresh Soviet-inspired aggressions across the European-Asiatic land mass, many types of United States planes can be flown across to prepared fields under their own power. Aerial tankers and transport planes are a further help in moving urgently-needed fuel, personnel, and compact supplies. To that extent, progress has relieved the strain on waterborne shipping. Once based abroad, however, our planes can operate for only limited periods on available stores of fuel and munitions. Fast convoys of tankers and the latest cargo ships may well fight through and supply immediate needs of the Air Force and other branches. But waterborne transportation is as essential as ever to any large-scale sustained war effort—a fact which appears to have escaped most of the American people and perhaps some of their leaders.

Not until the Korean war bogged down in material shortages did the overall shipping situation receive much public attention. Then, typically, there were confused pros and cons. Although the Korean deficiencies were not due to lack of transportation, part of the press made it appear that the nation lacked sufficient cargo ships to meet even that relatively small movement. There were reports that the embarkation of the First Marine Division was held up by inadequate transportation. The Military Sea Transportation Service, a unified water

transport for all branches, headed by Rear Admiral William M. Callaghan, U. S. Navy, cleared the air by announcing that no shortage of ships for Korea existed and that MSTS was time-chartering vessels from commercial operators under normal procedure to augment its own fleet of fifty transports, forty-eight tankers, and twenty-five cargo ships, plus fifty-one smaller craft.

At about the same time, the All America Defense Association, headed by Robert K. Christenberry, a New York hotel executive, called for a careful study of the American merchant marine and its wartime capacity. "Since the end of World War Two," Christenberry charged, "the merchant marine has been cut adrift." He said there was grave doubt that the merchant marine could meet the transoceanic demands of an allout war without accelerated shipbuilding.

## SHIPPING LOSSES IN PAST WARS, A YARDSTICK

Anyone who could prophesy shipping losses in a global war might also come uncannily close to predicting the outcome of the war. In the absence of such a seer, one imperfect yardstick is available in the form of our losses in two previous World Wars. These figures, however, should be handled with care. Anyone applying them should take into consideration a number of strategic factors: (1) The fact that Germany's U-boat campaign off American shores in World War I was both belated and puny. (2) The development of more accurate and deadly submarine-air warfare in the second war. (3) The variety and menace of the improved weapons available for a third war at sea. Above all, it should be kept in mind that by far the greater portion of the World War II onslaught on merchantmen was launched in the Atlantic and adjacent waters by the Nazis. The Japanese underseas doctrine of saving torpedoes for naval craft unquestionably served to minimize our merchant losses in the long reaches of the Pacific. Another foe in that area might not be so kind.

The pattern of destruction of merchant shipping in the past two wars is clear. In each, weapons of attack were developed and exploited ahead of the counter-weapons of defense which eventually nullified them. In the first war German underseas boats ran wild until curbed by the establishment of the convoy system and later by the laying of the North Sea mine barrage to hem them in. In the second war, magnetic mines took a steady toll in European waters until foiled by degaussing gear. Next wolf packs of submarines, sometimes working with aircraft spotters, made serious inroads on transatlantic convoys until hunter-killer groups of escort carriers and destroyers or DE's, operating on the "seek-out-and-destroy" principle, intercepted them before they could attack convoys.

Whether submarines can get away with murder at the start of a third war, before being arrested by the latest anti-submarine craft and devices, remains for the test of actual warfare to reveal. Quite possibly special radar search planes with M.A.D., the new 2425-ton hunter-killer destroyers and the highly-maneuverable 750-ton antisubmarine subs developed by the United States Navy will prove more than a match for snorkels and other underseas innovations. Just because enemy submarines prevailed in the early stages of two wars does not mean that they can do so in a third, especially in these inventive days.

But one thing is certain and painfully elementary. Unless adequate naval-air protection is available from the opening gun in today's split-second warfare, an enemy can take such a heavy toll of

merchant shipping in a short period that it may delay or change the outcome of the war. History speaks bluntly in this respect. Until checked by the convoy system, U-boats brought Britain to the verge of starvation. Early in 1917, they were sinking British shipping at the appalling rate of 1000 vessels a year and nearly 600,000 tons a month. Yet that rate of destruction pales beside the devastation wrought early in the subsequent war. At the peak of submarine warfare in 1942, Allied shipping losses averaged 687,000 gross tons a month around the calendar.

The damage done to the American merchant marine, especially, was far greater in the more recent war. To compare: The invasions of Belgium by the Kaiser's field-green hordes in 1914 set off a series of merchant sinkings which cost us, before and after we entered the conflict, 151 merchant ships of 315,588 gross tons. Among them were approximately one-tenth of the steamships we owned at the start of the war.

From the time Hitler's Nazis swarmed over Poland in 1939 until the final gun of that war, 1554 American merchantmen of 6,277,077 gross tons were sunk through enemy action, convoy collisions, and other wartime operational risks. Conceding that the second war lasted twice as long, American losses nevertheless amounted to ten times the ships and twenty times the tonnage sunk in World War I. Currently the most significant facts are these:

Our World War II losses exceeded the total number of merchantmen we possessed at the start of that war. Not only that, they exceeded in numbers, though not in tonnage, our present active merchant fleet. In fact, World War II cost us nearly 25 per cent more ships than we have in active service today.

A repetition of such sinkings in a future transoceanic war would place the issue of victory or defeat squarely on two things: Our reserve merchant fleet and our shipyards.

### THE STATE OF THE NATION'S MERCHANT MARINE: WHAT HAVE WE?

On paper, in round numbers of ships and gross tonnage, the merchant marine of the United States never looked better. It is far more tangible than some of our other paper preparations for defense. Unfortunately, part of it may disintegrate like paper boats under attack by fast new submarines.

It is true, as has been pointed out, that the merchant fleet is in better shape than it was in 1917 or 1941. This perfectly valid comparison should not be seized upon by Pollyannas, however, as proof that all is well. We are better off today to about the extent that a boxer who is up on one knee is better off than one who is flat on his face (1917) or down on both knees and one hand (1941). By no means are we up on both feet and rarin' to go. And our opponent, in terms of the potential shipping problem to be licked, looks to be bigger than ever.

Merchant shipping operated under the American flag as of July, 1950, consisted of some 1200 vessels of about 9,500,000 gross tons, as compared with 1103 steamships of 4,287,000 gross tons in 1914 and 1398 vessels of 8,134,000 gross tons shortly before the outbreak of the war in 1939. Not only is the present-day fleet of greater overall tonnage; it is relatively freer of obsolete craft such as the leftover "Hog Islanders" from World War I which cluttered our merchant marine in 1939, and most of it is modern enough to steam 14 knots or better.

In types of ships, the nearest thing to a deficiency appears to be in passenger vessels suitable for conversion to fast transports. Many of the 33 liners now in commission are relatively small. Six liners, including a mammoth of 48,000 gross tons and several twenty-three knot ships half that size, are nearly in service

or will be in service between now and April, 1952. Our tanker fleet, a prime submarine target and contributory cause of a severe oil shortage in World War II, now consists of some 416 ships of more than 6,000,000 tons compared with 384 ships of slightly more than 4,000,000 tons on September 1, 1939. In addition, many of the 185 now under the Panamanian flag are American-owned and presumably available in a pinch. The balance of the active merchant marine is made up of 655 dry-cargo ships, 509 of them sizable ocean-going craft in foreign trade.

Another 2250 or so merchantmen, all of them dry-cargo craft except for nine small oilers, were moored in backwaters as a merchant fleet reserve as of midsummer, though some have since been pressed into service. This impressive standby force is far greater numerically than anything we had early in World Wars I and II. The total of laid-up ocean-going ships 15 months before Pearl Harbor, for instance, was 198 ships of 1,110,868 gross tons.

The misleading thing about the existing merchant marine reserve is that its large numbers may obscure its relatively questionable value in time of war. Seventy per cent of the reserve consists of slowpoke Liberty Ships with a rated speed of only 11 knots. Many failed to make even that in the pinches of the past war when new. Eight and nine-knot convoy speeds imposed largely by the presence of these ships, in fact, led to the belated construction of the faster Victory Ships, good for 14 to 17 knots.

Like the Hog Islanders which burdened our peacetime shipping economy for decades, the Liberties have old-fashioned reciprocating engines instead of more modern turbines. The builders are hardly to blame. If anyone is, the nation is. For in the desperate rush to build ships in 1942-43, only reciprocating engines could be made in sufficient quantity with the available tools and material, and there was no time to retool.

The sad facts concerning these ships are summed up in the official Government report, "The United States at War," which frankly says they were unofficially named the "Ugly Ducklings" and their speed "was slow, 11 knots." The report adds, "The plans for this ship were adapted from a British tramp-steamer type and called for the older triple-expansion reciprocating engine, steam-driven winches and other auxiliary equipment no longer used on standard ships or naval vessels."

As an emergency speed-up measure, the Liberty Ships justified themselves in terms of swift construction. Building time was reduced from a year in 1941 to an average of less than two months in 1942, and Henry J. Kaiser's Oregon Shipbuilding Corporation turned out one Liberty in the record time of 14 days. But hasty construction is hardly ever an asset in the long run.

It may be noteworthy that a score or more of Liberty Ships were deliberately scuttled to make artificial breakwaters for the Normandy beachheads in 1944. Under the circumstances, they were regarded as highly expendable. While scarcely a conclusive comment on the worth of Liberty Ships in general, that ignominious use certainly points up the question of their military value today.

Too, age and inactivity have hardly quickened the reserve vessels. Although often termed a "mothball fleet," the preservation problems and methods with these ships differ greatly from the Navy mothballing technique. The division of combatant craft into many small compartments that can be closed off by watertight doors lends itself to the excellent dehumidification program worked out by the Bureau of Ships. Cargo craft, by contrast, are in effect vast seagoing caverns when unloaded. Dehumidifying more than 2000 of them was regarded as costly and impractical, and an oil and oxide method of preserving machinery and moving parts was adopted instead.

To recondition reserve ships requires, at a minimum, drydocking for hull survey and for scraping and painting bottoms. In instances where extensive repairs are indicated, the work may extend for weeks or months. The hurried breaking-out of hundreds of reserve ships could create shipyard bottlenecks in time of emergency. This is especially true if it coincides with a sudden urgency for repairing combat-damaged vessels.

In any case, if sent to sea again, the Liberties with their World War I speed may be harassed by World War III submarines able to operate *underseas* at approximately double the convoy speed and armed with improved torpedoes. It does not take the salty acumen of a graying convoy commodore to foresee the sickening risk—not only to the ships and crews but to the whole portion of the war effort entrusted to them.

## HOW READY ARE THE SHIPYARDS?

Whether to replace slow ships that have been sunk or equally slow ships that have been condemned as unfit for the quickened pace of modern warfare, American shipyards may be confronted by a sudden demand for fast new cargo carriers. If so, a third global war will resemble the past two in becoming a race against time to build ships. The past record in this respect is not a happy one.

During the two years of American participation in World War I, privately-owned shipyards delivered 506 cargo, tanker, and passenger ships of 2,301,257 gross tons, including most of the ninety launched with gala pomp and circumstance at Hog Island, below Philadelphia, one Fourth of July. But the bulk of their production, 1268 ships of 6,540,643 tons, was not delivered until after the Armistice, in 1919-20-21.

During the four years of the second war, the shipyards improved on their record considerably. They launched and completed 4915 merchantment of 36,960,592 tons—nearly four times our present active merchant marine. Part of this miracle, however, was achieved by such expedients as installing reciprocating engines in Liberties. Had the shipyards been given a go-ahead earlier, no doubt they could have done much better in that respect and perhaps in others. In any case, they demonstrated an enormous capacity and ability for turning out ships in awesome numbers. How much of it is left?

Early last summer, H. Gerrish Smith, President of the Shipbuilders Council of America and spokesman for more than 200 private yards, summed it up. "The present and prospective activity in the industry," he said, "is not now sufficient in volume to maintain that degree of efficiency necessary to have an adequate core of shipbuilding and shiprepairing 'know-how' available to meet another emergency readily."

By every index from humans, in terms of employment, to steel in terms of consumption, the shipyards have taken one of the worst peacetime beatings of any heavy industry. Scarcely one of every twenty wartime workers of 1943 is still on the job. And an industry which absorbed nearly 20 per cent of the national steel output in 1943 now uses about one per cent.

Fifty-seven of the leading construction and repair organizations, whose total payrolls went up from slightly more than 100,000 persons in the spring of 1941 to 1,006,895 at peak activity in 1943, reported that their total staffs during the last quarter of last year numbered only 50,094—less than half of the prewar figure. By far the sharpest cutbacks befell new-construction workers rather than repair personnel. Where the industry's payrolls as a whole were reduced to five per cent of peak strength,

new-construction staffs were cut back to three per cent. Carefully-trained and built-up wartime organizations have, perforce, long since been scrapped. And as recently as this fall, the New York Shipbuilding Corporation of Camden, engaged in building two large liners, was forced to lay off 1000 construction workers when changes in the liner plans to make them more readily convertible to transports, delayed the launchings from fall until next spring. The 1000 were laid off indefinitely, for lack of sufficient smaller or standby projects to keep them busy, at a time when big industries in other fields were eagerly hiring and staffing to fill war orders.

Cargo-ship construction received its biggest shot-in-the-arm since World War II this spring when private yards began building 25 fast freighters of the new "Mariner" class under contracts awarded by the United States Maritime Administration, headed by Vice-Admiral E. L. Cochrane, USN (Ret.), former Chief of the Bureau of Ships. Significantly in terms of possible wartime use, the new vessels are expected to develop almost double the speed of the old Liberties.

## PRIVATE SHIPYARDS AND NAVAL CONSTRUCTION

Under the private enterprise system which is the economic keystone of American democracy, industrial shipbuilders have constructed 77 per cent of all United States Navy combat vessels commissioned between 1914 and 1949. These units represent 73 per cent of the displacement tonnage of the fleet during that period and included the following types: Battleships, battle cruisers, carriers, light carriers, escort carriers, heavy and light cruisers, submarines, destroyers, destroyer escorts, frigates, gunboats, and minelayers.

During 1917-18 the private yards produced 82 fighting ships of 108,777 displacement tons. Navy Yards in those years completed 18 ships of 45,697 tons. In 1942-45 the private yards devoted in whole or part to naval construction turned out the astonishing total of 1012 ships aggregating 2,492,150 displacement tons. Navy Yards, with only a quarter to a third of the personnel, built 309 fighting ships of 871,060 tons. To the Navy Yards fell much of the burden of developing and perfecting new types of ships according to Bureau of Ships specifications, but both they and the private yards performed prodigiously by any standards.

Mammoths of the industry, such as the New York Shipbuilding Corporation, the Newport News Shipbuilding and Drydock Company, the Electric Boat Company, and others have been known to produce more combat craft of one or several types, alone, than the total strength of such type in sizable foreign navies. At one time, it was said that the battleship-carrier-cruiser contributions of New York Shipbuilding Corporation to the United States Navy considerably exceeded the total striking power of the French Navy in its World War II prime. Other yards have contributed as notably.

In its annual report last April, the Shipbuilders Council of America summed up the naval construction program in private yards as follows: "Prior to World War II, peacetime naval construction constituted an important source of work for the larger private shipyards of the country. Since the cessation of hostilities, however, there have been very few contracts from the Navy. In fact, no contracts for naval vessels were placed with private shipyards in 1949. . . ." Orders for the so-called "super carrier" of 65,000 tons, a 27,500-

ton Alaska-class cruiser, and two anti-submarine subs, the report continued, were canceled.

Whether it is wise for a nation that has relied so heavily upon private shipyards for its fighting ships to cut them off so abruptly is certainly worth a second thought on the part of those who do the Government's high-level thinking. For in naval construction, as well as in cargo-ship building, shipyard capacities bear a vital relationship to victory in any future trans-oceanic war. For example, only a limited number of anti-submarine combat craft have been completed—far fewer, certainly, than would be required to meet the far-flung demands of a global war. Pearl Harbor caught us dependent largely upon four-pipe destroyers and wedge-nosed Eagle boats, left over from the previous war, and sent us into an uncertain rush to build DE's along British lines. Today we know fairly well what new types of anti-submarine craft we want. Whether we can get enough of them in time depends upon shipyard production capacity.

## PEACETIME FEDERAL AID, AND WHOM IT AIDED

One thing that has done nothing to stabilize and insure the production capacity of American shipyards has been the Government policy of helping foreign competitors back onto their feet with American dollars, while at the same time "retrenching" in regard to subsidies for yards in this country.

Under the Economic Cooperation Administration, the United States supplied foreign shipyards with steel, engines, machinery parts, lumber, machine tools, concrete for repairing bombed drydocks and piers, and other essentials. No official figures on the amount or extent of this aid have been compiled, but there is strong feeling that it considerably exceeds subsidy payments to American shipyards for new construction. Some of the foreign aid, notably to shipbuilding centers like Britain, Japan, and the Scandinavian nations, may be partially justified as a military measure on grounds that it builds up our construction potential in case of war. But many of the aided nations are so exposed to Soviet attack and Communist sabotage that there is a legitimate question as to how long their shipyards might be able to function in wartime.

In this country, Federal aid to shipbuilding in recent years never has bulked as large as agricultural subsidies, for example. "Construction cost absorption," as it is labeled in United States Bureau of the Budget reports, amounted to $9,049,000 in 1940. Then it went by years as follows:

| | |
|---|---|
| 1941—$34,696,000 | 1945—$33,803,000 |
| 1942—$36,203,000 | 1946—$81,006,000 |
| 1943—$45,250,000 | 1947—$75,385,000 |
| 1944—$19,234,000 | 1948—$ 6,780,000 |

Throughout the entire period from 1934 through 1948, shipbuilding subsidies paid through the United States Maritime Commission amounted to a total of $341,013,000—some millions less than the figure given in official reports as the total loss on purchase and sale transactions of the Reconstruction Finance Corporation during the same period.

## CONCLUSIONS

1. Through circumstances largely beyond their control, American shipyards constructed the majority of their World War I merchantmen too late for that war and were forced to build a number of relatively inferior vessels in World War II because of time and material limitations imposed upon them.

2. A new global war may create the greatest demand for waterborne transport that the world has known. If history repeats itself again, the war will also evolve new methods of attack on merchant shipping with high initial losses.

3. The number of American merchantmen sunk in World War II exceeds the present total of our active merchant fleet.

4. Losses inflicted on the existing fleet can be replaced only by new construction or the activation of reserve fleet ships, many of which are so slow as to be of questionable worth in modern warfare.

5. In either case, there will be a great and sudden demand upon shipyards for construction or overhaul as the case may be. Large orders for anti-submarine combat craft are also likely.

6. While Allied shipyards and merchant marines may render valuable service, as in the past, the extent and continuation of this cooperation is contingent upon the fortunes of war and many of our Allies are in exposed positions.

7. The present state of our own shipyard industry verges upon industrial anemia due to undernourishment. New construction forces have been reduced to approximately three per cent of wartime peak strength and repair forces to five per cent.

8. If we are to rely heavily upon private shipyards, it would be well to energize them with something more than crumbs from the heavily-laden table of our peacetime economy. Dollars spent now may save lives later.

# S. S. "ATLANTIC SEAMAN"

## The Engineering of a 30,000-Ton Supertanker—The First Ship Using 1020 F Steam

ACKNOWLEDGMENT

This article was written by LESTER M. GOLDSMITH, Chief Engineer, The Atlantic Refining Company, Philadelphia, Pa., and a member of the American Society of Naval Engineers. It was presented at the Annual Meeting of the American Society of Mechanical Engineers in New York, November 26-December 1, 1950, and was published in the May, 1951, issue of "Mechanical Engineering." Some of the figures have been omitted in this reprint.

With the ending of World War II and the rapidly expanding demand for petroleum products, it was realized that the domestic supply in this country would have to be augmented by bringing crude oil from the Middle East. About two years ago, therefore, the author was given the task of developing a suitable tank vessel design for this purpose. For bulk transportation of oil in tankers, it is axiomatic that the largest practicable ship is the most economical, and this is more emphatically true for long-haul service from foreign oil fields. In line with this reasoning, the vessel described in this paper was the largest tanker ever laid down at the time construction was started.

### HULL DESIGN

The following principal dimensions were decided upon as being the maximum in view of the depth of water at ports of call and in the Suez Canal and the available number of dry docks of sufficient size:

| | |
|---|---|
| Length over-all..... | 660 ft |
| Breadth ..... | 85 ft |
| Draft, loaded..... | 34 ft |

A speed of 16-17 knots was decided upon as being desirable for the service intended and in line with modern practice. The maximum block and prismatic hull coefficients considered suitable for this speed without abnormal expenditure of power are of the order of 0.74 and 0.75, respectively (based on load-water-line length). A midship section coefficient of 0.982 with bilge radius of 6 ft and dead rise of 11 in. in 42.5 ft (half-breadth of the ship) completed the necessary fundamentals to enable a set of hull lines to be laid down. In connection with the 11-in. dead rise mentioned, it is noted that a number of the latest large tankers have been designed with flat-bottomed midship sections. This is an advantage for the designer, as it enables him to obtain finer ends on the hull for a given displacement, but the author's company believes that for satis-

factory draining of tanks, when pumping out, a moderate dead rise is very desirable. With a flat bottom, it is necessary to list the ship first to one side and then the other, to drain the tanks completely, and this tends to complicate and delay unloading. A lines plan was completed, embodying the foregoing dimensions and coefficients, and an extensive series of model tests were made at both the Experimental Model Basin at Stevens Institute of Technology and the Navy's David W. Taylor Model Basin in Washington. These tests confirmed closely the preliminary estimate of 16,500 hp for 17 knots speed, with some margin for sea conditions, on a loaded displacement of 39,350 tons.

Modifications of the hull lines were tried out but involved some loss of valuable displacement and were discarded in favor of the form originally laid down.

Three propeller designs were tested and the characteristics of the best one are given in the inset table in Fig. 1, which also gives the final model basin horsepower and rpm curves, etc., for the loaded condition of the ship. These compare favorably with most of the other recently designed supertankers for which similar data have been published. All these, at 16 and 17 knots, show a greater shaft horsepower per ton of displacement than the *Atlantic Seaman,* except in one or two cases where the rpm are lower, and the propulsive coefficient therefore somewhat higher.

Hull construction follows what has become practically universal tanker practice, i.e., twin longitudinal bulkheads and longitudinal framing. Based on Atlantic's experience with five 500-ft all-welded ships for eleven years, without any trouble from brittle fractures, the entire hull fabrication on the present vessels should have been by electric-arc welding. However, due to the fact that the cause and cure of fractures in welded ships is still under investigation, with progress made but no final answer reported to date. the American Bureau of Shipping and the U. S. Coast Guard took the pessimistic view that cracks are still possible, and therefore crack stoppers must be provided to lessen the chance of their reaching serious proportions. Consequently, it was necessary to build the hull with eight riveted longitudinal seams extended over the amidship three-fifths of the vessel's length. Since riveted seams have always been a tanker operator's headache, it is probable that those on the subject vessels may prove to be more trouble than they are worth, to say nothing of the 45 long tons of extra steel which the laps add to the ship's weight. This is equivalent to 315 bbl of crude-oil cargo which, needless to say, we would have preferred to add to the ship's capacity.

Another hull detail, more in line with modern progress in welded ship construction than riveted seams, is the serrated design of all longitudinal frames on shell, deck, and longitudinal bulkheads. These frames consist of reversed flanged plates and angles with a row of openings cut along the welding edge. These openings average about 8 in. in length and vary from 2 in. to 4 in. in height, depending on the depth of the bar. The inner corners are cut with generous radii, and the spacing, about 16 in. center to center, gives welding legs about 8 in. long. This construction results in a better distribution of material, saves weight, reduces welding, and the openings facilitate drainage and cleaning of tanks. It is the author's firm belief that continuously welded longitudinals act as integral parts of the shell plate, and therefore, in case of fracture, fail with the plate. This seems to be borne out by published photographs of fractured tankers, which show that continuously welded longitudinals have failed flush with the break in the shell. We do not believe this would have occurred if the longitudinals had been intermittently welded, as the hull plate could fail without causing a fracture in the stiffener.

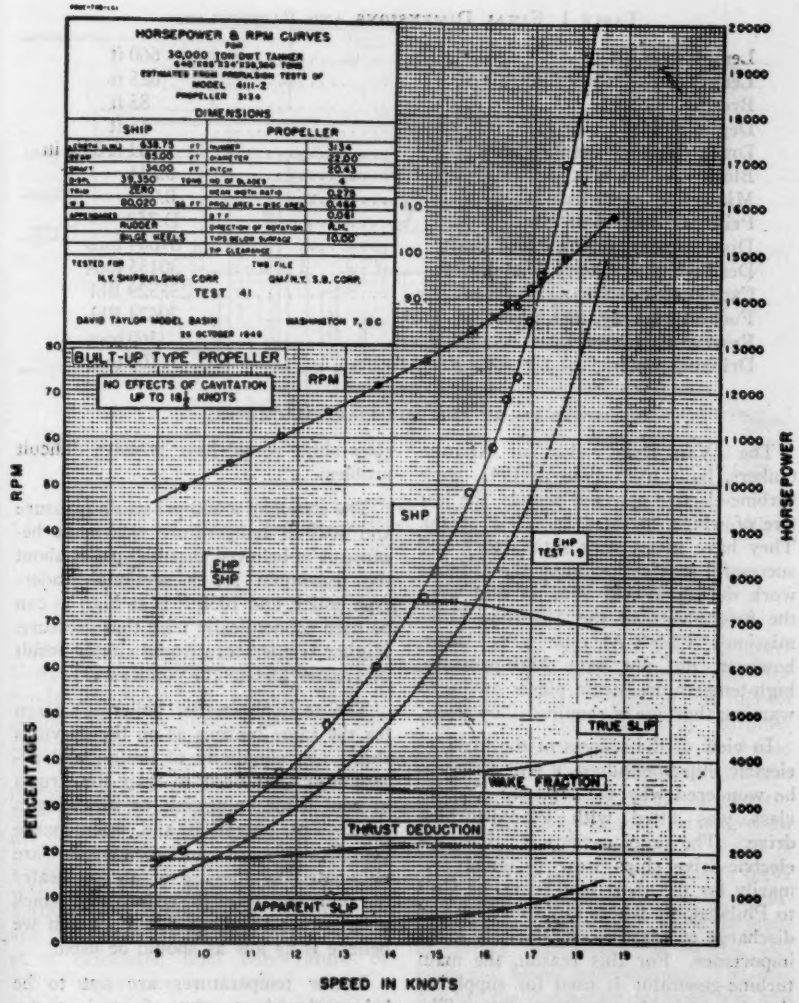



FIG. 1.—Model Basin Curves—Loaded Condition

Accommodations for officers and crew are laid out to provide a maximum of comfort, convenience and safety, with not more than two men berthed in any stateroom. All room bulkheads and lockers are either steel or asbestos-composition panels and furniture is of enameled steel or aluminum.

The ship is equipped with all modern navigation aids, including gyrocompass with gyropilot, course recorder, sonic depth finder, radio direction finder, loran and radar.

Final finished dimensions and other particulars are given in Table 1.

TABLE 1 FINAL DIMENSIONS AND PARTICULARS

| | |
|---|---|
| Length over-all | 660 ft |
| Length between perpendiculars | 625 ft |
| Breadth, molded | 85 ft |
| Depth, molded | 45 ft |
| Draft, statutory summer load | 34 ft 3 3/16 in. |
| Block coefficient | 0.744 |
| Midsection coefficient | 0.982 |
| Prismatic coefficient | D.758 |
| Displacement, summer load draft | 39664 tons |
| Dead-weight capacity, load draft | 30155 tons |
| Cargo capacity (max) | 257529 Bbl |
| Fuel-oil capacity, incl. reserve | 29674 Bbl |
| Reserve feedwater | 360 tons |
| Drinking water | 100 tons |

## POWER PLANT AND AUXILIARY MACHINERY

The "Van Dyke" class of Atlantic tankers, built from 1938 to 1941, were turbine-electric-powered vessels, the last five of which operated on 920 F steam. They have given very satisfactory and successful service including the arduous work during World War II and were the forerunners of the Maritime Commission's T2-SE-A1 type. The latter, however, did not have high-pressure, high-temperature steam plants owing to wartime shortage of required alloy steels.

In view of the success of the turbine-electric ships mentioned, it will doubtless be wondered why the *Atlantic Seaman* class was fitted with geared-turbine drive. The explanation is that the electric-drive ships were designed primarily for the short haul from the Gulf to Philadelphia where rapid loading and discharge of cargo is of relatively great importance. For this reason, the main turbine-generator is used for supplying the current for large cargo pumps. The new vessels, on the other hand, are designed for the long haul from the Near East which is a 43- to 45-day round voyage where unloading time is of much less importance than economy of full power at sea over long periods. Also the space requirements of an 18,000-hp turbine-electric plant, as compared with the 5000 hp on the Van Dyke class ships would have posed a difficult problem.

The choice of a 650-psi steam pressure and 1020 F temperature was made because it is believed that 650 psi is about the maximum for a sectional-header-type boiler, and 1050 F is as high as can be used economically with that pressure. Higher temperature would simply result in greater loss to the condenser.

The sectional-header boiler is chosen for the same reasons as on the previous ships, i.e., simplicity of design and accessibility—no need to wait for drums to cool before plugging or renewing a tube. The operation and maintenance complications of an economizer are eliminated by the use of an air heater of sufficient size to reduce the stack temperature to about 325 F, which we believe is as low as should be used.

Lower temperatures are apt to be below the dew point of stack gases, when using low-cost fuel with high sulphur content, and may cause excessive corrosion of the heater tubes. Reference to the heat-balance diagram, Fig. 2, will show that a feedwater temperature of 315-320 F is obtained by means of bleed-steam heaters, and we believe this is higher than obtained on other modern vessels using economizers.

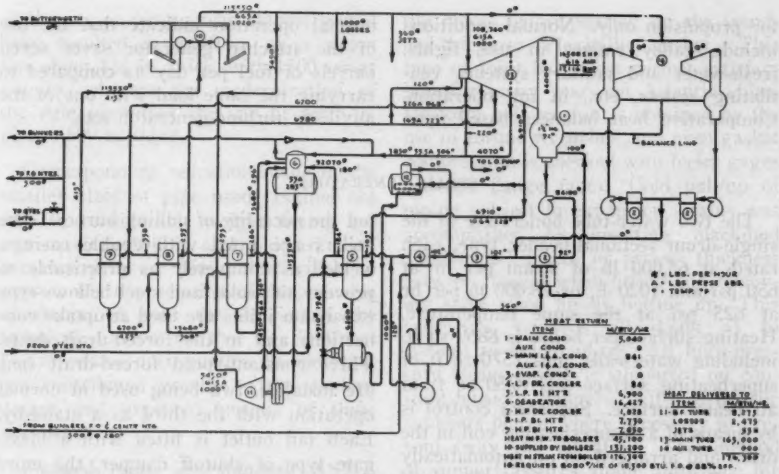


FIG. 2.—Simplified Material and Heat Diagram of S. S. *Atlantic Seaman* (As calculated for normal power operation using "attached" generator for auxiliary power)

## HEAT BALANCE

The heat balance is based on four bleed stages from the main turbine. The condensate at 28.5 in. vacuum, 92 F is pumped in series through the inter- and aftercondensers, evaporator condenser, low-pressure drain cooler and low-pressure heater to the deaerator. The feed pump takes suction from the latter which is some 50 ft above it, in the engine hatch, to provide positive suction. The pump discharges through a high-pressure drain cooler, intermediate and high-pressure heaters to the boilers at a calculated final temperature of 415 F as previously stated.

In order to reduce scaling to a minimum, evaporators are operated at approximately 3 psia, using the lowest available bleed-steam pressure. A connection is also provided to the low-pressure heating-system steam supply so that operation in port may be had when necessary. The deaerator has a triple function. It serves not only as a deaerator, but also as a direct-contact heater for the feedwater and a desuperheater for the service steam used for bunker and quarters heating, the fuel-oil heaters and the emergency turbine-driven lubricating-oil pump. It should be noted here that desuperheated steam is not used on this vessel for any auxiliary. This heat-balance arrangement gives a predicted economy of 0.473 lb of 18,500-Btu fuel oil per bhphr or 0.491 lb per shphr for normal running conditions, these figures being based on manufacturers' guarantees for boilers, and main and boiler-feed turbines. The reason for the distinction between bhp and shp just given is the fact that the main propulsion unit has an attached auxiliary generator driven from the intermediate gear shaft. This unit normally supplies all the auxiliary electric power required by the ship, and the 0.49 lb per shphr mentioned is, therefore, the total for all purposes under the predicted normal conditions and not the net figure

for propulsion only. Normal conditions include galley ranges in use, lights, fresh-water and sanitary systems, ventilating system, etc., in full operation. Comparative heat balances based upon normal operation indicate that the use of the attached generator saves seven barrels of fuel per day as compared to carrying the same load with one of the auxiliary turbine-generator sets.

## STEAM GENERATORS

The two water-tube boilers are of the single-drum sectional-header type, each rated at 65,000 lb of steam per hr at 650 psi and 1020 F, or 78,000 lb per hr at 625 psi at the same temperature. Heating surface per boiler is 8869 sq ft, including waterwalls, plus 2570 sq ft of superheating surface and 8750 sq ft of air-heater surface. Superheat control is by means of a desuperheating coil in the drum and arranged on an automatically controlled by-pass ahead of the third pass of the four-pass superheater. This by-pass comes into operation at about two-thirds normal load, below which it is not needed. This type of superheat control has been entirely successful on nine previous ships during the past twelve years, and it has never been necessary to renew a turbine blade due to heat damage. Boilers are each equipped with four double nozzle wide-range burners which incorporate an invention of the author consisting of a small center tip spraying through a larger outer one. A three-way cock allows either or both tips to be used and provides a very wide range of operation (9 to 1) without the necessity of pulling burners. The boilers are fitted with double casings, welded as completely as practicable to prevent air leaks, and steel bellows-type expansion joints are used at uptake connections and in the forced-draft ducts. Three constant-speed forced-draft fans are installed, two being used in normal operation with the third as a stand-by. Each fan outlet is fitted with a blast-gate type of shutoff damper, the more usual butterfly type not being considered sufficiently airtight. Air heaters are designed with two passes on the air side and are equipped with by-pass dampers to prevent sooting up under low load or stand-by conditions. Boilers are fitted with continuous automatic air-puff soot blowers operating under 200-psi air pressure which insures adequate blowing. They blow alternately, first on one boiler and then on the other, a complete cycle requiring about three hours. The use of air-puff soot blowers, rather than steam blowers, prevents loss of valuable distilled water and does a satisfactory job if sufficient air pressure is used.

## MAIN STEAM PIPING

The design of the main steam piping for 1020 F presented somewhat of a problem since the ABS and USCG rules at the time did not contemplate temperatures of this order, nor did they include allowable stresses for such alloys as 2 per cent chrome, ½ per cent moly, or 2¼ chrome, 1 moly, which latter it was finally decided to use. Fortunately, both of these agencies were found extremely open-minded and co-operative, and the recently published "Interim Guide" was developed and adopted in time to use in designing the steam piping for the subject vessel. The flanges also were given special consideration, which enabled us to use the 900-lb series slightly thicker than standard instead of the 1500-lb series which a strict application of the rules would have required. Some idea of what this co-operation meant in weight saving may be gained from the fact that extrapolation of the rules existing when a study

of the steam piping was started would have resulted in a 10-in. main steam line about 1¼ in. thick, with 1500 series flanges, whereas the modernization of the rule permitted the use of an 8-in. pipe, 0.509 in. thick.

Corresponding reduction made in the smaller sizes of pipe used resulted not only in considerable weight saving but increased flexibility and reduced temperature stresses. The author wishes to express his appreciation of the valuable assistance of both the ABS and the technical section of the U. S. Coast Guard whose open-minded co-operation has contributed greatly to the modern design and expected success of these vessels.

Flanged joints are standard ASME male and female type with ¼-in. raised face and ¼-in. recess which allows an appreciable entry of the raised face into the recess before seating on the standard-thickness Flexitallic gasket. This type of joint has given perfect satisfaction for many years on Atlantic ships. Uniform bolt tension is obtained by the use of torque wrenches, and even gasket compression is checked with feeler gages between flange faces. Cold pull-up of piping subject to expansion strains was accomplished by inserting machined "dutchman" pieces of proper thickness between flanges when fitting and removing same when finally bolting up. This procedure removes all doubt as to amount of cold pull-up. All high-pressure steam piping is supported on constant-tension hangers with hydraulic snubbers placed where necessary to prevent sway and vibration. This method of support assures ample allowance for expansion and minimum stress at the connections to the various units of machinery.

## MAIN PROPULSION UNIT

The main propulsion unit is a cross-compound steam turbine with double-reduction gear, a two-pass condenser and attached 700-kw auxiliary generator, driven from the starboard intermediate pinion shaft. The entire unit complete with lubricating-oil pumps and coolers, inter- and aftercondensers, steam jets, control-valve manifolds, gland steam system, and all interconnecting piping was supplied by the turbine manufacturer. The high-pressure turbine is an impulse-reaction type, and the low-pressure turbine a single-flow reaction type, with astern motor at the exhaust end. The exhaust trunk is welded directly to the condenser inlet to eliminate possible leakage of a large flanged joint. Condenser tubes are 70-30 cupronickel which we have found have a life of more than ten years when used in conjunction with the double-bottom deaerating tank described herein. Three lubricating-oil pumps are built into a well in the gear case, one bevel gear driven from the main bull-gear shaft, one a steam-turbine-driven unit which starts up automatically when oil pressure drops below a set minimum, and an electric-motor-driven pump to be started manually in emergencies or when the main turbine is shut down and is being driven by the turning gear. It should be noted that no gravity lubri-

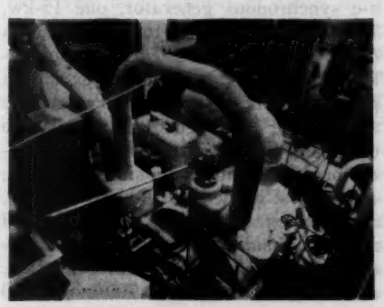


FIG. 3.—Main Turbines of S. S. *Atlantic Seaman*

cating-oil tank is fitted or required. It has been the author's experience that overhead tanks for gear lubrication will pull air into the system, and it is well known that oxygen in a gear case is detrimental to gear life. A further precaution against the entrance of oxygen into the gear case is a special packing gland around the main drive shaft. The gears are arranged in what is generally known as the nested pattern and reduce the turbine speeds of 6450 and 4280 rpm to a propeller-shaft speed of 100 rpm at normal full load.

## THRUST BEARING

The main thrust bearing is not a part of the gear assembly, but is a separate Kingsbury type double, eight-shoe unit located aft of the reduction gear so that no thrust load is carried into the latter where it might cause distortion of the case and consequent misalignment of the gears. The thrust bearing is provided with a self-contained oil cooling system and is supported on a foundation long enough to carry two self-aligning steady bearings, one forward and one aft of the thrust bearing. Provision has been made for future installation of a thrust meter, if desired. A shaft torsion meter is also installed for measurement of horsepower.

## AUXILIARY MACHINERY

*Auxiliary Generators.* Electric power and light for the ship is supplied by two geared-turbine generator sets, each consisting of one 750-kw 60/50-cycle, 450-v, a-c synchronous generator, one 15-kw, 125-volt, d-c generator for miscellaneous direct-current requirements, and one 15-kw, 125-volt, d-c machine for excitation purposes. These two auxiliary sets are also of the "package" type, similar to the main unit, with turbine and generators all mounted on a single bedplate, condensers welded to exhaust nozzles, air ejectors and other accessories all arranged in a compact unit. The generator attached to the main gear case, already mentioned, is a 700-kw, 60/50 cycle, 450-volt, 600-rpm machine which is used to carry all electric auxiliaries when the ship is at sea, running steadily under normal full-load conditions.

The 750-kw auxiliary turbine-generator units are arranged so that either one may be operated as a synchronous motor, taking current from the attached generator and dragging its turbine on which vacuum is maintained through a connection to the main condenser. When the attached generator speed falls to approximately 52 cycles, due to necessity for slowing the ship, the speed governor automatically starts to open the steam admission valve so that the auxiliary turbine assumes the full auxiliary load by the time the attached generator has slowed to 50 cycles. A circuit breaker between the attached generator and each of the auxiliaries opens automatically, when one of the latter takes over, and prevents it from trying to motor the attached machine. This breaker's opening also brings the turbine set up to 60-cycle speed and automatically starts up the condensate and circulating pumps for the auxiliary condenser. When the attached generator is again above 52-cycle speed, the turbine unit can be returned to "motorized" operation. This is a manual operation. The two generators are synchronized, the circuit breaker is closed, the water pumps stop, and the speed governor on the auxiliary turbine is reset at its lower limit of 52 cycles. This cuts off the steam but leaves the governor ready to open and causes the turbine to reassume the load if the attached generator speed again drops below 52 cycles. This system has been in use for years on the Van Dyke class ships, is entirely successful and

reliable, and has been applied to the T-2 tankers owned by the author's company as well as others.

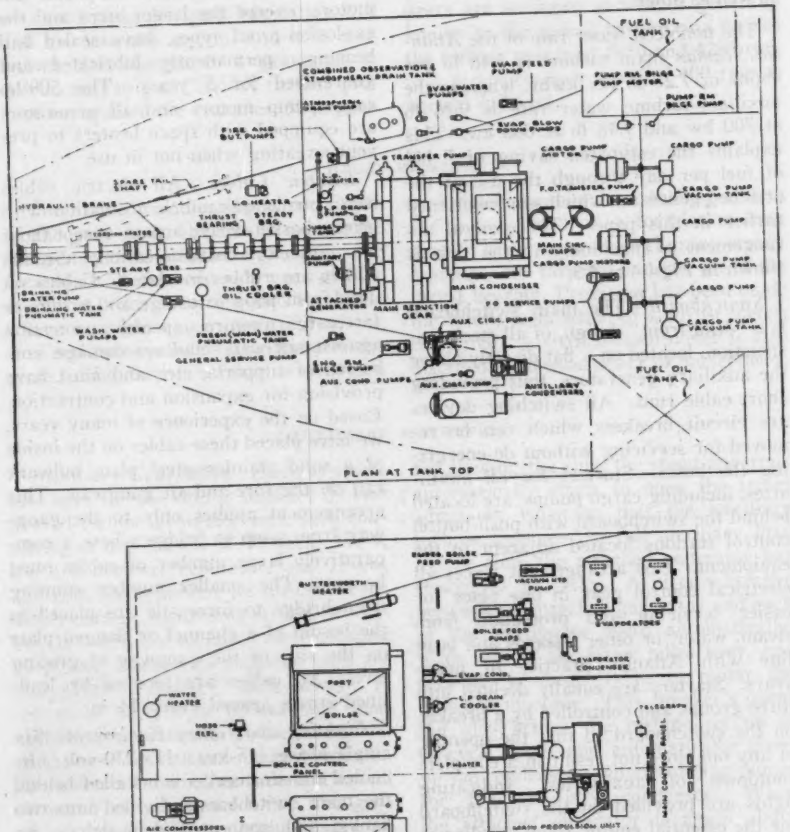
The nonbleed water rate of the *Atlantic Seaman* main turbine is 5.48 lb per shphr or 7.25 lb per kwhr, whereas the auxiliary-turbine water rate is 9.26 lb at 700 kw and 9.48 lb at 600 kw. This explains the estimated saving of 7 bbl of fuel per day through the use of the attached generator which was mentioned earlier in this paper. The general arrangement of machinery in the ship is shown in Figs. 4 and 5.

*Switchboard.* The main switchboard is a "dead-front" design, of all-steel construction, located on a flat directly above the auxiliary generators, thus providing short cable runs. All switching devices are circuit breakers which can be removed for servicing without de-energizing the buses. Starters for all auxiliaries, including cargo pumps, are located behind the switchboard with push-button control stations located adjacent to the equipment. This arrangement places all electrical control gear in one place for easier servicing and protection from steam, water, or other hazards and is in line with Atlantic practice of many years. Starters are equally divided into three groups and controlled by a breaker on the switchboard so that the opening of any one does not result in a complete shutdown of auxiliaries. Indicating lights are provided on the switchboard for the essential engine-room auxiliaries and steering-gear motors, and these are automatically restarted in proper sequence in the event of complete power failure. Automatic transfer equipment, both 450-volts a-c and 125-volts d-c is connected ahead of the generator breakers to provide uninterrupted power supply to the steering gear and lighting system in the event of breaker opening.

*Motors.* All a-c motors, other than a few small sizes operating on lighting circuits, are 440-volt, 60-cycle, 3-phase, Class 2, marine-type, totally enclosed, except those in hazardous locations which are Class 1, explosion-proof. All motors, except the larger sizes and the explosion-proof types, have sealed ball bearings, permanently lubricated and guaranteed for 5 years. The 500-hp cargo-pump motors and all generators are equipped with space heaters to prevent sweating when not in use.

*Electric Cables.* All electric cables have varnished-cambric insulation with bronze basket-weave armor, except those for interior-communication circuits which are rubber-insulated. Cables on deck from poop to bridge and bridge to forecastle require special protection against salt-water and sea damage, corrosion of supports, etc., and must have provision for expansion and contraction. Based on the experience of many years, we have placed these cables on the inside of a solid stainless-steel plate bulwark rail on the fore-and-aft gangway. This arrangement applies only to the gangway from poop to bridge where a comparatively large number of cables must be run. The smaller number running from bridge to forecastle are placed in the bosom of a channel or flanged plate on the side of the gangway at grating level. All cables are secured by lead-lined straps spaced every 14 in.

*Lighting and Galley Equipment.* Six single-phase, 15-kva, 115-230-volt air-cooled transformers are installed behind the main switchboard, divided into two banks, and connected delta-delta. An induction-motor voltage regulator is connected on the primary side to maintain constant voltage. One of these banks supplies current for the lighting system and the other for the galley range, bake oven, etc. Fluorescent lamps are used for lighting quarters and incandescent lamps with vapor-tight fixtures in other spaces. There are no cables, wires, or lights inside the main pump room which is illuminated through bulkhead or deck deadlights with fixtures on the outside. In other locations considered hazardous, class 1 explosion-proof fixtures are used.







FIGS. 4-5.—Arrangement of Machinery

## AUXILIARY ENGINE-ROOM EQUIPMENT

*Salt-Water Deaerating Tank.* The use of a deaerating tank built into the double bottom of the ship has proved so phenomenally successful on the Van Dyke class ships that its adoption for the present vessels was a foregone conclusion. All salt-water pumps in the engine room take suction from this tank which is fed through large high and low sea chests, port and starboard, and this arrangement eliminates the need for other sea connections. Vent pipes from the top of the tank extend well above the water line and serve as constant vents for entrained air coming in through the sea chests. Two vertical centrifugal main circulating pumps are set directly above the deaerating tank, and all pump-suction pipes extend close to the tank bottom where the chance of picking up air is a minimum. Each of the main circulators supplies one side of the condenser but a crossover is provided so that if one pump fails the other can supply both sides.

*Boiler Feed Pumps.* Two six-stage, 350-gpm, centrifugal, boiler feed pumps are each driven by a 250-hp turbine taking steam at full boiler pressure and temperature as do the auxiliary generator turbines. It is believed that whatever slight loss in economy there may be in this arrangement, it is more than justified by the elimination of reducing valves and other complications incident to providing steam at various pressures and temperatures. The exhaust from these turbines is used in the deaerator for feed heating so that the heat in this steam is returned to the plant.

*Instrumentation.* In line with modern practice and to facilitate keeping the power plant at maximum efficiency, a number of recording and indicating instruments are installed. Steam flow and temperature from each boiler are recorded, the flow, pressure, and temperature to the main turbine, and the flow and pressure to the auxiliary turbine-generators. Combustion air and stack temperature for each boiler are recorded, and a salinity recorder is provided for checking the purity of boiler feedwater leaving each of the condenser hot wells and the drains inspection tank.

Automatic combustion control (steam flow-air-type) is installed to maintain a constant outlet pressure from the boilers. Automatic two-element feedwater control is used to maintain constant level in the boiler drums, and constant superheat temperature is kept, as previously mentioned, by an automatically operated bypass through a desuperheating coil on the boiler drum.

In addition to the foregoing, a sufficient number of indicating thermometers and pressure gages has been installed so that the operating condition of any part of the plant can be determined easily. Provision has also been made for the installation of test gages, themocouples, and thermometers for obtaining more complete heat-balance data during tests than normally would be possible with the permanent instruments installed. It is the author's belief that the instrumentation outlined is far ahead of anything heretofore placed aboard a ship. It is not, however, ahead of good land-plant practice, and why the same engineering standards are not maintained on marine propulsion plants is still a mystery to the author.

## CARGO PUMPING SYSTEM

Three single-stage, motor-driven, centrifugal cargo pumps are located in the pump room just forward of the engine room. Their combined rated capacity is 20,000 bbl per hr which is sufficient to unload the ship in about 12 hours. The pumps are driven by 500-hp motors located in the engine room and connected

by jackshafts with flexible couplings extending through stuffing boxes on the bulkhead.

The use of electric power for cargo-pump drive instead of steam turbines required, of course, large auxiliary generating sets, but eliminated the complications of the steam and condensate system which the turbine drive would have involved. A study of cost also revealed that the electric system adopted, including the extra cost of the larger generating sets, was cheaper than the steam plant would have been. No stripping pumps or stripping lines are used, the stripping operation being accomplished with entire satisfaction by having the main cargo pumps automatically and continuously primed by vacuum priming pumps. This arrangement has been an Atlantic practice for many years and, as stated previously, is completely successful, saves weight and complications, and speeds up unloading by permitting the cargo pumps to run at full capacity until tanks are practically empty.

## DECK MACHINERY

Deck machinery consists of the anchor windlass and one warping or dry-cargo winch on the forecastle deck, two warping winches on the upper deck, and two warping capstans on the aft end of the poop deck. All these machines are hydraulically operated from two 125-hp electric-motor-driven hydraulic pumps, one located forward and one aft, and arranged with the necessary automatic valves so that all units may be operated simultaneously or independently. The A-end hydraulic power units are both located below decks so that no electric motors are required to be outside, exposed to weather and salt water. The advantages of hydraulic drive with its great flexibility of speed control are well known, and it is believed that this is the first time it has been applied to all deck machinery on a ship.

## VENTILATION

Ventilation of machinery spaces is by means of propeller-type fans inside and below the deck-cowl trunks which can be rotated in the usual manner to face the wind. The fans assist the natural air flow and force air to the various delivery points in the engine and boiler rooms. There is also an exhaust duct and fan drawing hot air from a hood above the auxiliary turbine-generator units and discharging to atmosphere above the fiddley top.

Both forward and aft quarters are equipped with forced-air distribution systems of sufficient capacity for a change of air every 4 min. When necessary, this air is heated to maintain a comfortable temperature in the rooms. In hot weather it is used for ventilation only and is supplemented by large attic-type exhaust fans which draw air out of the passageways and the rooms opening into them. These fans have about 4 times the capacity of the forced-air fans, in order to insure very adequate air circulation in hot weather.

In addition to this system, all washrooms, bathrooms, and laundries have individual exhaust fans of capacity to provide an air change every 2 min. The galley is provided with a 3000-cfm fan exhausting from the hood above the electric range.

### STEERING GEAR

The steering gear is of the conventional electric-hydraulic type with two horizontal-opposed rams connected to a crosshead on the rudder stock and with power furnished by duplicate Hele-Shaw type oil pumps driven by 125-hp motors. Steering is by two entirely independent electric controls using Selsyn motors on separate circuits from bridge to steering gear.

One of these controls is arranged for either hand or automatic steering through the usual gyropilot and is a full follow-up self-synchronizing system. The alternative control is a non-follow-up type operated by a small lever on the right-hand side of the steering column. Any of the three systems is instantly available to the helmsman without moving from his position by shifting the three-point selector lever on the left side of the steering column. In addition to the three methods of steering from the bridge, there are four emergency hand-steering stations aft, one at the forward end of the boat deckhouse top and three in the steering-gear room—the latter consisting of a trick wheel for direct control of each hydraulic motor, and the third a four-man hand pump for use in case of failure of both power pumps.

### PERFORMANCE

The most intriguing engineering is of little value unless it results in performance in accordance with design. Delayed delivery of the *Atlantic Seaman* resulted in the completion of the maiden voyage only a few days before this paper was presented. Consequently, performance data to date are somewhat sketchy.

The hull has surpassed our most optimistic predictions. At designed speed there is a minimum of water disturbance and air entrainment is exceptionally low. The bow and stern wave patterns are remarkably flat and smooth for a vessel of this speed, indicating a minimum waste of power in wave-making. The ship answers her rudder quickly, and on trials with helm hard overturned a tight circle of about 0.6 mile in diameter. On the maiden voyage, in ballast condition, the horsepower meter on the shaft indicated an average of 16,031 shp at 100 rpm with a speed of about 18.6 knots. Within limits of accuracy of observation and without the usual allowance for sea conditions, this is an exact check on predicted performance.

The constancy of steam temperature and pressure under automatic control is almost unbelievable. Fig. 6 is a reproduction of a chart from the meter measuring steam flow to the main turbine. The trace nearest the center is pressure, the middle trace temperature, and the outer one steam flow. The slight variations from smooth traces shortly after 4:00 a.m. and 4-hr intervals thereafter, are caused by inspection of burner tips by each watch. Steam temperature did

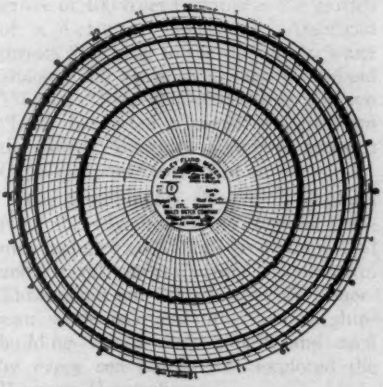


FIG. 6.—Steam Flow Chart

not exceed design maximum, even during a crash stop. The oil burners described elsewhere in this paper performed as expected and it was not necessary to change tips or remove burners for fluctuating loads varying from stand-by to overload.

A measurement of fuel consumption, during a 24-hr period of the ballast run, showed a consumption of 7986 lb with a horsepower reading on the torsion meter of 16,031 shp which gives a figure of 0.498 lb per shphr. This was obtained with vacuum of 27.9 in. Corrected to design vacuum of 28.5 in., the figure becomes 0.489 lb per hphr, which checks with design expectations. This, it should be noted, includes fuel for all purposes; no attempt having been made to eliminate any normal use of power during the test period.

The maiden voyage of 3720 miles (sea passage) was made at a speed of 18.5 knots in ballast and at 18.09 knots loaded, without a shutdown of the power plant. After completion of the first voyage, obstructions, consisting of a pair of pants, a shirt, and a sock were found in the cascade seal pan of the main condenser so that perhaps the author may be pardoned for predicting further improvement under more nearly normal conditions.

# MILITARY MARINE WOOD USAGE—MARINE LAMINATING

ACKNOWLEDGMENT

This paper was presented at the Fifth Annual National Meeeting of the Forest Products Research Society in Philadelphia, Pa., in May, 1951. The author is JOHN G. KUENZEL, Senior Materials Engineer, Bureau of Ships, Navy Department. The article is particularly timely in view of the large number of wooden ships now under construction.

## INTRODUCTION

Marine laminating is an exact technical art born of World War II shipbuilding needs for large high quality structural timbers. The Bureau of Ships is traditionally dependent upon lumber and timber of the highest grades available from domestic and foreign forests. Those of us in the Bureau of Ships concerned with specifications and quality control of forest products for marine usage recognize that this tradition has been a heritage from the earliest written records of shipbuilding. The Phoenicians, Romans and later European countries successively exploited the choice Lebanon cedar of Mediterranean forests so completely that today only a small grove of 100 trees remains in the garden of a Lebanese monastery. American forests first rang to the shipbuilder's axe almost 1000 years ago when Greenland Vikings "Eric the Red" and his son "Leif" harvested a cargo of logs from the North American mainland between Cape Cod and Nova Scotia.

The first cargoes shipped to England from the Plymouth and Virginia Colonies included cedar logs from Cape Cod and naval stores from Jamestown. Throughout our early history the American white oak and other choice shipbuilding woods were sought and used by every sea power that explored the Western Hemisphere.

## WOODS FOR SHIPBUILDING

The course of history which has led to United States naval supremacy has in our times left its battle scars on our forests. In 1944 the Navy required 9,000,000 tons of steel; during the same period 3,000,000 tons of wood were required for all types of naval military construction, afloat and ashore. It is becoming increasingly difficult to meet the requirements for shipbuilding timbers from our domestic old growth trees. Despite promising recent developments in structural aluminum and molded plastic boat hulls, wood continues to serve many important shipbuilding needs. Wood is our only naturally renewable structural material. It is significant that the present shipbuilding

program gives high priority to wooden vessels of non-metallic, non-magnetic, laminated design.

Sawn timber products used in naval construction are of three types: Utility lumber, structural timber, and special boat and shipbuilding lumber. The first type consists essentially of construction or yard lumber generally stocked in grades of No. 1 Common and Better hardwoods and No. 3 Common and Better softwoods. A wide choice of domestic woods from every lumber producing region are procured under grade-marking rules of the various lumber associations to provide the advantages of a competitive market and broad geographical supply sources. Such lumber serves countless purposes including the fabrication of intricate model ship designs at the David Taylor Model Basin utilizing cherry lumber from Pennsylvania, and white pine from Idaho or California; submarine battery wedges made at Philadelphia Naval Shipyard from New England beech or maple; and laminated small boat members and keel blocks made of Douglas fir, southern pine or white oak at several shipyards. Lower lumber grades are also procured at all shipyards for pallets, boxes, crating and dunnage.

The quality of structural timber and special boat and shipbuilding lumber must conform to certain basic principles of design. These materials for use in stage and scaffold plank, shipdecking, planking and framing timbers must be stocked in the highest grades and largest sizes available and their procurement, therefore, presents the greatest problem from the standpoint of available supply.

The principal woods used by the Navy on the basis of quantity required are Douglas fir, southern pine, "other softwoods," white oak and "other hardwoods," in the order named. Considering shipbuilding needs alone, white oak ranks second in the volume required. "Other softwoods" include cedar (southern white, Port Orford, Alaska, and western red), cypress, hemlock, larch (tamarack), pine (white, sugar, ponderosa, red, and lodgepole), redwood, spruce (Sitka, Engelmann, and white). "Other hardwoods" include ash, balsa, basswood, beech, birch, cherry, cottonwood, gum, elm, hickory, ironbark, lignum vitae, mahogany, maple, teak, and yellow poplar. The uses for these woods have been evolved through many years of shipbuilding. Because the timbers of tremendous size cut from old growth trees are not always available in the quantities and grades required from eastern and southern forests, the shipwright's choice for material has shifted to suitable species of large size in the Pacific Northwest, Alaska and tropical America.

White oak, because of its structural superiority and durability, is an important component of many types of wood hull Naval vessels, including thirty-five designs of patrol, landing, district craft, minesweepers, auxiliary transport, salvage and rescue vessels ranging from 70 to 183 feet in length and over twenty-five designs of small wood boats up to 63 feet in length. Steam bent or sawn bolted frames, keels, stems, skegs, shaftlogs, knees, stern posts, and deck beams for many of the 50,000 wooden craft in our two-ocean Navy of World War II utilized white oak.

The total white oak requirements for the present wood shipbuilding program are tentatively estimated at approximately 30,000,000 board feet. This is equivalent to approximately one-sixth of the 1950 production of this species in grades of No. 1 Common and Better. The ships will be several years in building, and provisions are made for utilizing treated red oak and other suitable alternate species. As a part of this program, the facilities of American forest products industries to produce laminated ship timbers are being studied for mobilization.

## MARINE LAMINATING

The development of marine laminates such as are specified in the present naval wood minesweeper program originated about 1939 or 1940. The process evolved for gluing large straight or curved ship timbers for the Bureau's gigantic needs utilized principles of laminated arch construction introduced in the United States from European sources, with one major distinction. The casein, and urea-formaldehyde glues found to be suitable for interior laminates in shore built structures delaminated in salt water. Modern phenolic resin glues such as have been used in marine or exterior type plywood since 1920 and cured in hot plate presses at temperatures of 350° F. were considered uneconomical in the production of large timbers. The Bureau explored the possibility of high-frequency curing of the high-temperature setting phenolic adhesives about 1941, but preliminary experiments were not promising, due to the variable dielectric properties encountered in large wood assemblies of the species and shapes required for ship timbers.

In 1942, when the need was great, the Bureau called a conference of synthetic adhesive manufacturers, presented the problem, and within 6 weeks their laboratories produced, with the help of a Divine Providence and American ingenuity, a resin adhesive curing at a lower temperature than the boiling point of water, and durable under extreme service exposure at sea. A great variety of laminated ship and boat parts have been produced for the Bureau (Fig. 1).

The Bureau of Ships may justly be proud of a part in this development, which is the first major contribution to wooden shipbuilding in 2000 years. One of the Bureau's ship designers informed me that he scanned wooden shipbuilding literature from the era of Viking ships to the present in the drafting of the hull

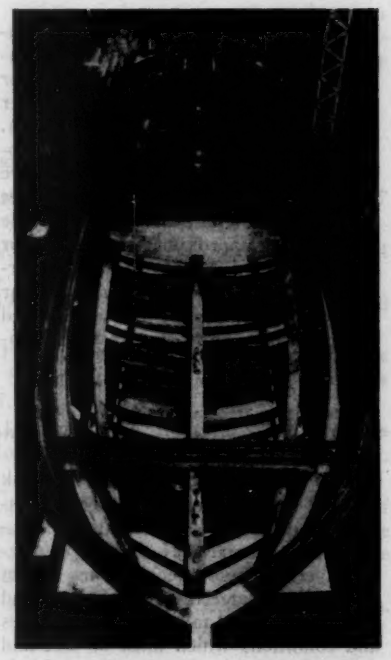


FIG. 1.—A forty-foot motor launch having completely laminated foundation including capping, deck frames, shaft log, stem, horn timber, transom, fabricated at the Puget Sound Naval Shipyard, Bremerton, Washington. (Official Photograph U.S. Navy.)

detail plans for a 165-foot wooden minesweeper. A volume published in 1863 on wooden ship design (*7*) describes methods evolved at the peak of large wooden ship construction, and represents accumulated knowledge from an almost forgotten generation of master boat builders and shipwrights working with the finest old growth timbers. When such a reference book is again published, the Bureau's present laminated ship design will mark a new era in this field.

## ADHESIVES FOR MARINE LAMINATING

The intermediate and room-temperature-setting adhesives of phenol, melamine, or resorcinol base formulated for marine laminating are procured under Military Specification MIL-A-397 (*1*). Adhesives suppliers are required to submit proposed intermediate temperature setting, type II class 2, marine service adhesives for approval testing. These tests require approximately 35 days for completion and include 21-day accelerated cyclic-exposure and block shear tests of laminated white oak beams cured in accordance with manufacturers' instructions. Acceptance of a marine service adhesive is predicated on performance of test beams in comparison with Standards derived from extensive investigations, also complete physical and chemical evaluation of the adhesive with respect to composition, acidity limitations, cleanability, liquid working life, and storage life. A Qualified Products List is maintained of approved adhesives, in which the curing temperatures and curing period maintained at the innermost glue line for each manufacturer's type II class 2 adhesive is shown.

## LAMINATING TECHNIQUES

Laminating procedures for white oak and for Douglas fir ship and boat members are described in specifications MIL-O-15154 (*2*) and MIL-F-2038 (*3*) respectively. These specifications list in detail the material requirements and closely controlled fabrication procedures and conditions which must be met and followed to produce acceptable prefabricated marine laminates of these species. A little less than 10 years of experience in laminating by several Naval shipyards and by private concerns specializing in laminated wood for naval construction have established the need for a relatively high temperature of cure to develop oak glue joints equal in strength to solid wood that resist delamination under extreme service conditions in seawater (*4*). A number of phenolic-resin and melamine adhesives cured at 190° F. at the inner glue line for 10 hours, and resorcinol adhesives similarly cured at 140° F. for 10 hours have successfully resisted delamination in white oak beams as shown by several years service use, and by weathering and accelerated cyclic-exposure tests conducted at Naval Shipyards and at the U. S. Forest Products Laboratory. Douglas fir, southern pine, white ash, and similar woods having lower density than oak have been successfully glued for boat and ship timbers using resorcinol adhesives cured at somewhat lower temperatures, for the same curing period. Each type of adhesive and each species of wood to be glued must be related to a definite laminating procedure based on performance requirements (*5*).

Laminating procedure specifications are being considered for such shipbuilding wood products as teak-Douglas fir decking, ash boat stock, scarfed long-length ship planking, and many other items procured by the Bureau. The research necessary to develop adequate material specifications is gaining momentum at many government, private, and institutional laboratories. Only through thorough, painstaking effort will this relatively young offspring of the forest products family grow into a modern progressive industry.

The challenges presented are worthy of the best technical skill we can summon. Primarily, these problems lie in the realm of wood preservation technology. Old growth timbers with their

large proportion of durable heartwood for the shipwright's needs are fast becoming nostalgic memories. Research to determine means for suppressing and completely arresting deterioration of woods subject to extremes of decay, weathering and marine-borer attack is the key to wider acceptance of a great variety of domestic wood species as a structural shipbuilding material. Laminating has only unlocked the outer door to this problem.

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# FREEDOM TO MEASURE: YARDS OR METERS?

ACKNOWLEDGMENT

The author of this article, which appeared in the June 22, 1951, issue of "Engineering," is H. S. ROWELL. He presents the case of those opposed to the adoption of the metric system in weights and measures in Great Britain.

"No man, nor any body of men, is good enough, or wise enough to dispense with the tonic of criticism." So wrote the great Huxley in the *Nineteenth Century* of March, 1887. He was then engaged in one of his disputations against pseudo-scientific theological dogma—no longer of much interest to intelligent people—but his aphoristic sentence is still up to date, and aptly applicable to the "New Despotism" revealed by Lord Hewart.

The Report of the Committee on Weights and Measures Legislation, which appeared on May 11, has, apart from an editorial article, received only scanty notice, even in the leading journals. No one has thought fit to administer, in adequate measure, the "tonic of criticism." This may be due to the difficulty which many people will experience in reading the 467 paragraphs, plus the five appendices; or, perhaps, the statement of Sir Hartley Shawcross in Parliament on May 10, "that the Government could not be regarded as in any way committed to accepting the Committee's recommendations on the Metric System" has lulled the alarm and blunted the interest which engineers and traders might otherwise have shown. In what follows, the more important inconsistencies of the report are noticed, the number of each paragraph referred to being given in parenthesis.

Thus: (6) "The main conclusion to which our enquiry has led us is that the existing principles of Weights and Measures law are soundly based and stand in no need of fundamental revision." By any standards, even of the Civil Service, this is a fairly clear statement, but it is followed by almost a full page of three provisos containing some very drastic recommendations. One of these (8) recommends "delegated powers of legislation to be wielded by the Minister within the broad purposes of an Act." . . . "We hardly need add that all delegated legislation should be preceded by full consultation with the parties likely to be affected by it." This sounds very sweet and reasonable; but, on turning to (18) we find that the Committee took evidence from "100 or so other associations representing manufacturers, traders and professional, scientific and technical bodies." Of these, "about half a dozen have advocated the adoption of a policy of a long-term transition to the metric system: the rest have stated that there has been little tendency on the part of members to use the metric system and have not favored any alteration to the existing position."

Inquiries by a number of women's organizations "reveal, as might be expected, that a very substantial proportion of the purchasing public is likely to be against abolition of the Imperial units in most common use." Thus out of about 100 associations concerned with manufacture "about half a dozen"—surely, the number could have been given?—advocated a long-term change-over to metric units and the rest, 15 or 16 times as many advocated no change. Despite this, and the adverse view of the women, and the previous statement (8) "that all delegated legislation should be preceded by full consultation with the parties likely to be affected by it," the Committee flout the evidence which they have collected and recommend the minority view of the long-term change. A similar piece of despotism occurs in (354). One section of the "liquor" trade stated that about ten years would be required for the exhaustion of their existing stocks of bottles. The Committee consider this long period to be unnecessary, and "that the Board of Trade need give no more than a 12-month warning period."

In (11) the Committee explain that the Report is severely compressed from the mass of evidence received; but, to one reader at least, either the evidence or the compression thereof seems to have been very unevenly distributed. Chapter 2, for example, on "The Adoption of the Metric System," has five pages—the same number as in Chapters 14 and 15 on "Fresh Fruit and Vegetables," and "Alcoholic Liquor," respectively. The Metric System, if completely adopted in 20, or even in 40 years, would bring an upheaval costing thousands of millions of pounds; the consumption of fruits and vegetables and perhaps of alcoholic liquor, will probably cause no serious disturbance. There is much useful information in the Report, but the lack of proportion in dealing with the various parts of the subject is a serious blemish. In no case is any attempt made to assess the cost of the changes recommended or the amount likely to be saved.

The most important part of the report, especially from an engineering point of view, is the five-page Chapter 2, on "The Adoption of the Metric System." This is grossly biased and full of shoddy special pleading. The metric system (14) is eulogized as "compact, closely defined and universally recognized," etc., whereas the Imperial system "is really a conglomeration of units which have in the past been found convenient for particular types of measurement." This is exaggeration almost to the bounds of distortion. Again, "there is no internationally-recognized body responsible for the Imperial system which can in any way compare with the International Metric Conference." The Imperial system was established centuries before the metric system was thought of. It has never needed an internationally-recognized organization to "put it over."

The Imperial system has grown from that of Rome during nearly 2000 years. In the Seville Museum, there is, or was 20 years ago, a Roman ounce taken from Italica. On the label the weight of the ounce is given in milligrams. The present writer had the thrill of converting this to English weight and found it agreed to about 1 part in 600. Here it is of interest to note that the *Libra* of Argentina is 1.0127 lb. Av., whereas the *Libra* of Spain and Mexico was 1.014 lb. Av. and the *Libra* or *Arratel* of Portugal was 1.012 lb. Av.—a very interesting conglomeration. To say that there is no "internationally-recognized" authority responsible for the Imperial system is almost shocking. What is the President of the Board of Trade?

In (23) the Committee "have found it difficult to obtain any very relevant evidence as to the way in which other countries have overcome the difficulties of transition," but they believe that most of the early Metric converts were using a multiplicity of local units and the

change-over was "a welcome rationalization of a confused situation" . . . "and the building of a single trading community within the nation." This is a well-known fact, and on record, and in some cases within living memory. France had many and various systems of weights and measures, of which few were reliable, in 1789; but it took 40 years, with threats of serious penalties, before the French people began to use the metric system. In Germany, the creation of Bismarck's Germany in 1871 gave an exceptional opportunity to coordinate the weights and measures of the various States into the metric system. In several cases the change was made without changing the name of a unit, so that the half-kilogram was called a German *Pfund*, a Dutch *Pond*, a Danish *Pund*, and so on.

Of a great many converts to the metric system, it may be said that there were hardly any of their systems worthy of any respect and many of the smaller countries seized on the metric system as providing a cheap, ready-made system which linked them respectably with greater nations. In contrast with this condition, consider England. Almost ten centuries ago, King Edgar (Emperor of Britain), with his great primate, St. Dunstan, laid it down that there must be only one system of weights and measures in the country. Under the Norman King Henry I, at Christmas, 1125, 94 moneyers were summoned to Winchester for debasing the coinage and had their right hands struck off. "And this because a man might have a pound, and yet not be able to spend a penny at a market." These facts explain in part why our metric problem is not of the same kind as that of France, Germany, China or Russia. In the Middle Ages, we had at Stourbridge, near Cambridge, the biggest fair in the world, with lesser fairs in other centers all using a single system.

In (15) the Committee praise the metric system, which (they say) has "appealed to technicians and scientists" from its earliest days on account of its ease of calculation ". . . and there is no doubt that, coupled with a decimal system of coinage, it offers many benefits to traders in respect of their day-to-day calculations, costings and invoices." This is quite incredible, and it is contradicted in (17), where the Report states, "it can with some justification be maintained that the actual units of the Imperial system are more convenient for everyday use than the metric and that, for many trading purposes, a quantity can be stated more concisely in Imperial terms than in metric and consequently with less chance of it being misunderstood." If the metric system has any superiority over the Imperial it is in its decimal structure, and this superiority is only of value to those who have to do many calculations—a very small fraction of the population. For simple arithmetic, the metric system seems to be inferior. Shop assistants and booking clerks on the Continent seem to need slide rules, pencils and paper, and more time than corresponding workers in Britain. In simple daily trades, even uneducated people become very expert in dealing with special units. In Britain, an acre is based on a morning's plowing and is defined in effect as a furlong (furrow-long to give a breather) by a chain (four poles—the ox-beam or pole). These are visual images to many country people, and acres are more real to them than the centimeter is to some scientists.

There is no export trade in acres and it is difficult to see why any change of unit is needed. There is no export trade in milk, so why should the established sizes—half-pint, pint, and quart—be altered to metric sizes? Who can possibly gain? There are more than 200 million milk bottles made each year. There are crates and various machines for cleaning, filling and sealing these bottles. What is to be gained by replacing these by metric sizes? The fact that is over-

looked by the metric enthusiast is that there are "tricks in all trades" and few men need to know more than one trade. Few men have any need to know timber measure (which is ignored by the committee). Whereas in science the metric system stands unchallenged, in crafts and trades the units and sizes of the trades are more convenient. Each for each, they have grown by use and survived by fitness.

For day-to-day trade, the metric system is bad in its nomenclature. Continental workmen of the best kind do not use such terms as myriagram, which the Committee recommends (142); and it is certain that British and American workmen with their love of pungent monosyllables, would never welcome the metric prefixes. A thousandth of an inch is a "thou" and a micrometer is a "mike" in most works, and it is a sound instinct that impels workmen of sense to use monosyllables. There can be no mistake in the use of the ton, pound, ounce, dram, quart, pint, gill, mile, yard, foot, inch, and so on; but, with the metric system, error is easy, both in regard to prefixes and decimal points. For example, one of the largest chemical companies in Britain, which uses the metric system exclusively, sent an order for 10 cubic meters of a rare compound, when only 10 cubic centimeters were required.

In (17), the Committee attempt to summarize the "external factors," whatever that may mean. They say that the metric system is used "by the overwhelming majority of countries in the world." In what sense "overwhelming"? Even if these countries have "the great proportion of the world's population," there is no weight in such a contention. In (18), as already pointed out, the Committee flouted 94 associations who were in favor of no change, and sided with "about half a dozen" bodies in favor of a long-term change. They do not believe in majorities, evidently, even when there is no difference of intelligence. They cannot possibly be entitled to use majority arguments when the majority consists largely of the ignorant.

Then again (17), "it is in the field of international trade that the benefits of uniformity of measurement come fully into their own." This is not correct. There are all kinds of imports and exports flowing in all kinds of units. Before the war, Belgian, German, and Czechoslovakian steel bars were sent to this country in English sizes and weights, and paid for in sterling. Ground-thread taps were sent here in Whitworth sizes from at least three Continental countries, and jig-boring machines of the highest accuracy were sent from Germany and Switzerland, graduated in inches. Or consider the wine and liquor trade. From the Rhine to the Douro and beyond, from Holland to the Rhone, the bulk of all liquor is sold in terms of the English ⅔-quart bottle. Why should the practice of a century, which is almost uniform all over Europe, be set aside and changed to metric? But the fact, above all, against this foreign trade idea, and it is a fact that a Board of Trade Committee ought to know, is that the foreign trade of a nation—even of Britain—is a small fraction of its internal trade. Why upset the internal machinery, on which all depends, and which has done so well for centuries, to encourage a small and tenuous fraction?

As to uniformity (17), it would be a blessing if the metric peoples would cultivate a little more uniformity. In Italy, they have no "kilogram"; instead, they have the "chilia" gram. The liter is spelt in various ways. Even in England, among the ardent metricists, we do not get uniformity. For example, in one of the largest chemical firms, they specify a furnace gas pressure as 100 milliatmospheres, whereas at the N.P.L., in recent tests on the effect of air pressure on chronometer rates, the air pressure was shown to visitors in mm. of mercury.

In (17) we find "It is obviously illogical for there to be two separate systems in a world which, from the trading point of view, is becoming rapidly smaller." It is well known that two World Wars have increased economic nationalism and that British export trade has suffered greatly as a result. In view of the many facts of history which show how trades and nations can decline as a result of invention, this argument of international trade is too thin to justify reforms costing billions of pounds. It is, of course, illogical for different nations to use different languages; and it is still more illogical for any one nation, such as Switzerland or Belgium, to use two or three languages. Wales and Eire might be brought into the International Metric Conference, if only to add to the "overwhelming" number of countries.

The arguments of logic are risky even for philosophers. The argument that only one system of measures should be used for all trades is equal in value to the statement that every man should be restricted to one overcoat or one garment. Engineering could not be done efficiently in the metric system of the scientist. The metric engineer has been compelled to develop a second system, which is not in a decimal relation to the basic metric system. The table below shows the two systems:

| | Metric Units in | |
|---|---|---|
| | Science | Engineering |
| Length .. .. .. | cm. | meters or mm. |
| Mass .. .. .. | gm. | 9810 gm. |
| Force .. .. .. | dyne | 981,000 dynes |
| Time .. .. .. | second | second<br>minute<br>hour |

Are these two systems logical? They are connected by the inertia of matter and they are useful on account of the essential need of the engineer to employ the muscular sense. Is it not illogical for the metric countries to use two standards of length? It may be, but it is sensible practice, for the standard meter bar at Sèvres is of platinum-iridium alloy and is one meter long at 0 deg. Celsius; but the engineer in metric countries uses a steel bar which at 20 deg. C. has a length of 1 meter. These two standards are useful and suitable for their work and they are, in fact, a "conglomeration" of two arbitrary standards. Is it logical for the Committee to approve the use of the "cran" in the herring industry or to make no protest against the immunity of the Scots sand and ballast trade to weights and measures law?

In (22) the Committee state that "the internal convenience of a decimal system of measurement could not be adequately realized unless at the same time the coinage was decimalized." This is perfectly true and very obvious but why is it left to a proviso? In the United States they have had a decimal coinage since

1786-92, and practical convenience has caused the use of the short ton of 2000 lb. But the fact remains that, in all countries in which a decimal coinage has been established, popular convenience has compelled the use of half coins.

In Britain, a scientific worker using the metric system is rarely concerned with money; it is the trader who is using weights and coins all day long and for trading purposes. We have not only the finest system of weights and measures but also the best coinage. If things are sold in grosses and dozens, we have twelve pence to the shilling, if in cwt., we have 20*s.* to the £, and so on in a variety of trades. On the London Stock Exchange, transactions are made in all kinds of currencies; stocks and shares are quoted in pence, shillings and pounds, with fractions and decimals mixed, as 6 percent of 1*l.* is 1*s.* 2.4*d.* It is hard to believe that any other currency is so flexible and convenient. It is almost completely decimal in its divisions, and many accountants already decimalize accounts in English money for certain purposes.

The fault of the decimal system either in weights and measures or in coinage is due to some psychological difficulty which is not easily described. If a man says that he weighs 217 lb., his mass is not so easily visualized as if he said 15 stone 7 lb., and this is still more so if 220 lb. and 15 stone 10 lb. are compared. In the same way, a bedroom rent at 15*s.* 6 *d.* is more tangible mentally than one at 755 francs. In this matter of coinage, Continentals frequently ridicule our use of the guinea; but in hotels or nursing homes the weekly rate in guineas is easily modified to a daily rate in shillings. With our system of seven-year covenants, a donation can be arranged for a charity to suit the strings of both the purse and the heart. The division of weights and measures and of money, is not psychologically on a par with decimals, which are a device for calculation. The division of a book is more nearly parallel. With two or more main parts divided into several chapters, each with paragraphs as required, the subject matter can be dealt with more easily than with mere numerical pagination and no "conglomerate parts."

In (74) the Committee recommend that a permanent commission should be appointed to advise the President of the Board of Trade "on the most suitable legal definitions of the derived units of capacity, temperature, heat and electricity and on the possibility of defining in law the unit of time," . . . "This Commission (77) should include the Astronomer Royal, the Director of the National Physical Laboratory and the President of the Royal Society sitting as ex-officio members." If there are doubts as to the superiority of the metric system for trade and manufacture, there must also be a little dubiety as to the desirability of mixing together the weights and measures of trade with the units and standards of science. In (29), for example, we read "units of area, capacity, electric current, and temperature." In Appendix C we have units of capacity listed as the gallon, quart, pint, etc. It would be preferable not only to separate "trader's" units very clearly, but also to use some such term as "volume" or "content" for measures like the "gallon," thus reserving the "farad" for capacity.

Lastly, it may be emphasized that for many years the cylinder bores, piston diameters and crank radii of English motor-car engines have been made in metric sizes, and no serious difficulty has been heard of in motor-car factories or garages or spare-parts organizations. If English workmen for many years have been able to make crankshafts, with pins in English sizes, and "throws" in metric sizes, it is difficult to understand how anyone can argue that there is a serious problem, or that to solve it

the entire Imperial system should be swept away. Certain units should be allowed to die out, as many have already done in quite recent years. Then, if our lb. and foot units are brought into agreement, as the Committee recommends (49-52), with those of the United States, the world has two systems of measurement which can continue to co-exist and help. The recent practice of the N.P.L. in stating the dimensions of important parts in both systems is a good one, and serves as a useful check and an aid to visualization.

# CURRENT WELDING RESEARCH PROBLEMS

ACKNOWLEDGMENT

This article, a report compiled by the Welding Research Council of the Engineering Foundation, was printed in "The Welding Journal," June, 1951. It consists of a compilation of welding research problems with which industry is confronted.

Some of the problems are not suitable for University workers because of limitations of facilities, time or money. If any University wishes to undertake research work on any of these problems it is suggested that they first contact the central office of the Welding Research Council, 29 W. 39th St., New York 18, N. Y.

The Council will assist in the formulation of the problem in supplying specimens that may be needed and grants-in-aid on approved projects.

## INTRODUCTION

Some 15 years ago the Engineering Societies created, under The Engineering Foundation, an organization now known as the Welding Research Council, to initiate, encourage and conduct research work on the complex problems involved in the fabrication of structures by welding.

The complexity of the problems is such that all branches of science are involved. The University Research Committee of the Council encourages researchers in the fields of pure science, as well as applied science, to carry out research work on some of these problems.

Affiliation with these activities provides the university and the research worker with unusual opportunities for recognition of accomplishments.

A conference of University Research Professors is held once a year, during the time of the National Metal Congress and Exposition. The Council annually makes available sufficient funds to pay for the railroad and pullman expenses of the professors who attend, with an upper limit of fifty dollars to any one professor or research worker. There is thus provided an opportunity for a university research worker to discuss his problems with leaders of industry and with other research workers in the field.

Through close connection with the American Welding Society opportunity is provided for the presentation of a completed piece of research in the form of a paper at the Annual Meeting of the Society, which also takes place during the time of the above-mentioned Congress and Exposition. Even though such a paper may not be presented, an opportunity is provided for its publication in a medium which reaches scientific workers throughout the entire world.

In order to stimulate such research the Welding Research Council presents an outline of current welding research problems.

This list represents a framework of research into which the University worker can easily fit his own activities without prejudice to either their independent character or fundamental nature. At the same time, however, he can use his inventive ingenuity on types of problems which, because of their value to industry, have a direct influence in raising our standard of living.

The problems listed here are not meant to be comprehensive or exclusive, but rather to suggest the kind of problems toward which the Welding Research Council wishes to direct interest.

While in many cases there has been an effort to refer to work completed, or in progress, on each problem listed, it should go without saying that any contemplated research should be preceded by an intensive survey of the past and present investigations on the subject under consideration.

In order to facilitate the compilation, the suggested problems have been arranged according to particular fields of research, and have been divided among the following selected headings:

I. Welding Physics and Chemistry.
II. Metallurgy.
III. Mechanical Properties and Testing.
IV. Structural Studies.
V. Resistance Welding.

When going over the suggested problems the University research worker will realize that many of these problems may be studied without knowledge of the welding process itself and without having welding equipment. Others may require the procurement of welded specimens, and payment of expenses. The Welding Research Council will assist by supplying specimens that may be needed and by grants-in-aid on approved projects. However, it is imperative to make plans well ahead of the time at which the research can be started, because of unavoidable delays in delivery of specimens and appropriation of money. Also, the planning should cover as many phases of the problems as feasible, in order to insure that individual projects may contribute to a unified picture of the problem as a whole. A comprehensive and adequate investigation of any problem frequently requires a series of student investigations, properly integrated and coordinated by an interested and enthusiastic professor. The publication of progress reports, of which the professor is co-author, tends to rouse the interest of representatives of industry and to accord recognition to the university and the professor.

## I. WELDING PHYSICS AND CHEMISTRY

Research in the physics and chemistry of welding falls into two categories:

1. Research on welded products.
2. Research on welding processes, or welding operations.

This list of Suggested Research Problems in Physics and Chemistry is subdivided into these two classes. It has been compiled partly from previous lists and partly from new suggestions. In a few instances, several collaborators have sent suggestions for research on the same subject. To preserve the outlook of each collaborator, each suggestion has been included in the list.

Basic to most research on welding operations and welded products are the thermal constants of commercial metals at high temperatures. The compilation of a table of constants and coefficients for commercial metals up to arc temperatures is suggested as a research problem of the first importance. Unfortunately, many of the thermal data for

the table have not been determined. Consequently, researchers on thermal studies of welding are handicapped at the outset.

*Suggestions for Research on Welded Products*

(Refer to the separate sections on "Structural Studies" and "Mechanical Properties and Testing" for additional suggestions.)

1. Determination of the magnitude and distribution of stress in welded joints, particularly in pipes and fabricated pipe turns.

This problem is, of course, very important and is not by any means limited to welded structures. A fundamental study of methods for studying stress magnitude and distribution would be a large task. A great deal has already been published on this problem and, also, the related question, "Do so-called stress relief treatments actually relieve stresses?" A specialized article dealing with the application of available information on the subject to welded structures would be useful. In order to have any real value, an article of this kind would have to be prepared by a highly qualified specialist in this field. A mere collection of abstracts, or literature reviews, would have little value.

2. The application of the theories of elasticity, plasticity and creep to welded joints.

3. A theoretical and experimental study of the resistance to high velocity application of stress, of different weld metals and combinations of plate and weld metal.

4. The re-enforcement of structures under load. The development of the conductivity formulas and graphs in Chapter 2 of the 1950 Edition of the *Welding Handbook* in terms familiar to structural engineers, with special emphasis on equation 5, page 64, and on the depth of the overheated zone.

5. Corrosion of Weldments. The particular aspect of corrosion phenomena brought about by welding has been studied quite extensively, but no satisfactory theory has been formulated. This is due undoubtedly in part to the complexity of the phenomenon, but a clearer picture is believed to be possible, if corrosion research were undertaken without regard to an immediate practical solution of the problem. The following fundamental aspects are proposed:

(a) Influence of metal dissimilarity.
(b) Influence of metallurgical structures.
(c) Influence of stress.

This last aspect has particular importance, because the process of welding implies the production of residual stresses.

The rusting of welds in mild and low-alloy steels, in the air and submerged, should be studied to determine whether the same principles apply to bare or slag-covered weld metal as to bare or scaled plate.

*Suggestions for Research on Welding Processes*

Each major welding process has many subdivisions. For example, gas welding may be subdivided into air-acetylene welding, oxyacetylene welding, oxyhydrogen welding and pressure-gas welding. Likewise cutting may be subdivided into oxygen cutting, lance cutting, powder cutting, and arc cutting, each of which, in turn, has numerous subdivisions. A researcher familiar with any of the processes knows that he can ask questions about the physics and chemistry of each process that experts cannot answer. Frequently the researcher has the mental and experimental facilities the expert lacks to approach the problems posed by his process. For this reason it is believed that, if the researcher will familiarize himself with the details of any given welding process, and break down the process into its physical and chemical variables and occurrences, the research problems that

he can attack will suggest themselves to him naturally.

(*A*) *Resistance Welding* (refer to the separate section on "Resistance Welding").

(*B*) *Arc Welding* (refer to bibliography being prepared by A.I.E.E. Subcommittee or Arc Research, R. C. McMaster, Chairman). 1. Mechanism of Metal Transfer in the Welding Arc. Development of instruments and techniques for the observation and measurement of metal transfer in the iron-iron welding arc, a classification of types of metal transfer and evaluation of factors controlling metal transfer.

2. Steady-State Properties of Heavy-Current Welding Arcs. Evaluation of temperature in the arc column, potential drops at the surface of the electrodes, current density in the arc column and at the electrodes, potential gradient in the arc column, heat produced in the arc column and at the surfaces of the electrodes with arc current, atmosphere, pressure, metal vapor and coating constituents as parameters.

3. Arc Stability and Methods of Stabilizing Arcs. Study of the various stabilizing circuits with parameters of: voltage gradient in the arc column, ionization potential of the arc atmosphere, current density and arc current, electrode materials and configuration, thermal time constant of the arc atmosphere, the recombination and diffusivity of electrons and ions in the arc atmosphere, the supply of vapors and gases from electrodes and coatings.

4. Influence of Atmosphere and Coating Ingredients Upon the Properties of the Welding Arc. Determination of the fundamental characteristics of the welding arc as functions of various atmospheres, especially their effect on the arc heat and heat transfer to the electrode and work.

5. The Influence of Metal Conditions Upon the Welding Arc. The characteristics of the welding arc as functions of: ionization potential of the metal vapor, the vapor pressure and rate of vapor production, the melting and boiling points, the thermal conductivity, the heat of evaporation, the temperature of the metal, and the geometry and cooling characteristics with refractory and readily vaporized electrodes.

6. Heat Transfer Mechanism Between the Arc and Metal Surfaces. Study of the electrode potential drop region to within a micron of the surface as to physical state, power converted into heat, heat-transfer laws, melting and vaporization of electrode metal, state of particles in the arc atmosphere at the electrodes and electrical properties of this region. Also the heat transferred to the electrodes by conduction, convection, diffusion and molecular dissociation.

7. High-Current Phenomena in Arcs Between Electrodes Other Than Carbon. Volt-ampere characteristics at currents in the positive-slope region, anode and cathode drop characteristics, determination of the current-carrying mechanism, current density and potential distribution in the main arc stream and in the anode and cathode drops, determination of the percentage of heat dissipation by radiation, convection, conduction and molecular dissociation, determinations of temperature distribution in the arc stream, determination of the effect of various atmospheres and pressures on the arc, the effect of magnetic stabilization.

8. An extension of Froome's cathode-spot current-density study to steady-state arcs. Fundamental information on spot mechanism could be obtained with cathode-ray and Kerr cell photographs.

9. Theoretical Treatment of Electron Emission by a Very High-Temperature Plasma Under the Influence of an Electric Field, as Basis for a Reasonable Theory of the Cathodic Processes in Metal Arcs. Work should include investigation of temperature concept. Essentially a theoretical investigation, the results of which then could be checked

by comparison with experimental data known.

10. Development of a method of measuring instantaneous arc temperatures with a view toward better understanding of arc stability.

11. Ionization of the arc. An exploration of the nature of the ions contributing to the conduction in arcs of various types would be valuable. The most attractive problems are:

(*a*) Source of charged carriers, whether electrode, base, coating or shield.

(*b*) Influence of the shield on the discharge.

(*c*) The nature of arcs using various metal electrodes.

A great deal of work has been done, or is planned, but the field is so vast that parallel researches appear desirable.

12. Distribution of energy in the welding arc. A quantitative measurement of the energy contained in and distributed by an arc deserves further investigation. The energies used in melting electrode, melting plate and radiated to the atmosphere and the manner in which they are affected by current, travel speed, plate temperature and coating should be determined.

13. A study of the relative influx of air into covered electrode arcs as a function of travel speed, arc length and weaving motion.

14. What causes the arc force pushing back against the electrode? Is it related to the gas content of the metal? Is it found with nonferrous alloys and in inert gas-arc welding and in submerged arc welding?

15. An oscillographic study of striking an arc. A quantitative method is required for determining ease of arc striking with an investigation of the following variables: a. c. versus d. c., superimposed high-frequency striking current, open-circuit voltage, composition of atmosphere, nature of striking surface, composition of coating on the electrode.

16. Electric conductvity of welding slags up to arc temperatures with particular reference to submerged arc welding.

17. An exploration of arc action, including visible length, short circuits and type of metal transfer, over wide ranges of current and voltage. The well-known standard covered electrodes should be studied as well as submerged arc welding. For submerged arc welding the electrode might be immersed in a crucible of liquid flux above the metal before current is turned on. Current-voltage determinations might be made with increasing gap between metal and rod (see paper by C. E. Jackson and A. E. Shrubsall, The Welding Journal, May 1950, pages 231-s to 241-s).

18. Problems in inert gas-arc welding. (*a*) Effect of Metal Vapor in Inert Gas-Shielded Arcs. How much vapor exists in the arc plasma and what is its effect on voltage gradient. If possible, develop theory predicting observed values.

(*b*) Arc Voltage. Relative portions of arc voltage due to plasma, cathode region, and anode for wide variety of currents, current densities, materials, and shielding gases. This study would provide a basis for further theoretical development of the atmospheric arc and would lead to better understanding of wire burn-off and plate melting in welding.

(*c*) Determination of Deionization Time in Atmospheric Arcs. Variation of time with gas shield, current and other variables.

(*d*) Effect of Gas Shield on Transfer Phenomena Using Bare Wires. Motion pictures of transfer and theoretical deduction of mechanism involved to reduce spatter in welding.

(*e*) Arc Radiation Losses. Measure radiation loss from inert gas-shielded arcs.

(*f*) The effect of $H_2$ and $H_2O$ additions to argon and helium on the stability of the inert gas-shielded arc with

thoriated tungsten, aluminum and stainless steel electrodes. The object of the research would be to demonstrate the effect of known percentages of $H_2$ and $H_2O$ in the arc atmosphere on the ease of striking an arc and on its steadiness using alternating current and both polarities direct current with and without superimposed high frequency.

19. Cooling rates. There have been very extensive studies in this field from the viewpoint of weldability. There are, however, some problems which require further study.

(*a*) Influence of high currents and speeds on cooling rates and also on weld contours.

(*b*) Extension of data and methods of analysis to other metals, such as stainless steel and aluminum.

20. Slag-metal relationships in welding. A study should be made of the oxygen and manganese contents of slag and weld metal for submerged arc welding and covered electrode welding. The object would be to determine the degree of deoxidation of various weld metals and the variables affecting deoxidation.

(*C*) *Gas Welding and Cutting.* 1. A study of the variation of the composition of the weld metal as a function of the flame adjustment in oxyacetylene welding.

2. A study of the causes of sparking in gas welding with mild steel and low-alloy steel rods.

3. A study of the origin of drag lines in oxygen cutting and the effect of nonturbulent oxygen jets.

4. A study of the characteristics of flames from different welding torch tips as a function of gas pressure. The characteristics to be studied are shape of flame, radiation from flame and velocity of gas for various gas-to-oxygen mixture ratios.

(*D*) *Pressure Welding.* 1. The pressure welding of commercial metals, similar and dissimilar combinations, should be studied to determine the effect of the following variables:

(*a*) Degree of plastic deformation required to secure a weld.

(*b*) Effect of the rate of application of pressure.

(*c*) Role of recrystallization, if any.

## II. METALLURGY

Since welding is essentially a metallurgical process, the field of metallurgy is expected to supply most of the information needed for successful welding. The word successful means producing weldments free of the three following defect: (1) cracks, (2) porosity (or nonmetallic inclusions) and (3) deterioration of usable characteristics of the material of which ductility is the most common and the most widely required. Each of these defects is by itself a problem of considerable magnitude, and it is feasible to study them separately, bearing in mind that in many instances they are interdependent to a great extent. Thus, cracking is perhaps the most alarming defect in welding, but considerable loss in ductility may be potentially as dangerous because cracking may then occur under conditions which are considered safe for the nonwelded material. Whatever phenomenon is being considered, the influence of the following factors appears immediately.

1. Base metal.
2. Weld metal.
3. Degree of restraint during welding.
4. Treatment before and after welding, both mechanical (for example, peening) and thermal (for example, the so-called stress-relieving treatment).
5. The welding process.

Each of these factors is defined in turn by several more specific and more fundamental variables. Thus, base and weld metal may be considered from the point of view of structural, phase or

chemical changes. The degree of restraint may be characterized by geometry, state of stress or amount of cold work, etc.

What is basically important is to reduce all of them to as many independent variables as possible. This is by no means an easy problem, and the value of a particular investigation is largely dependent on how successful it has been in varying only one factor, while keeping the others as constants.

Much of the metallurgical work performed in the field of welding research has been based on the more thoroughly investigated fields such as the heat-treatment of steels. This is true of the many studies of the relationship of hardenability to weldability and the general studies relating weldability and composition.

Although the investigator has been hampered in his attempts of simplifying experimental procedures, many investigators have shown their ingenuity in design and execution of test programs. In the following section will be mentioned some of the general contributions to the field of welding metallurgy and comments will be included, regarding many problems which have not been investigated sufficiently to produce a generally accepted explanation.

### (*A*) *The Welding of Steel*

A number of articles have covered the general problem of welding plain carbon and low-alloy steels, the materials generally used for investigations of the weldability problem. Preliminary discussions have appeared in the *Research Supplements* to The Welding Journal, for example, Vol. 24, June 1945, page 313-s and Vol. 28, June 1949, page 246-s. The third edition of the *Welding Handbook*, page 79, contains a rather extensive chapter on the "Fundamentals of Welding Metallurgy."

A rather extensive effort is under way in the preparation of a Monograph on Weldability. This monograph will present a general survey of the metallurgy of welding together with tables of recommendations for the welding procedures for many specified grades of steel covering a wide range of chemical composition, thickness and intended uses.

Based on a survey of the information available in welding metallurgy, the following problems are suggested as worthy of further note:

1. There is need for a simple test of weldability which can be correlated with service.

2. Much work still remains to be done on the effects of welding on the notch sensitivity of steel and the reason for the change from ductile to brittle type of failure. It is hoped that future investigations in this field will strive to attack the problem more from a theoretical rather than an empirical point of view. The many investigations in this field and the efforts of the Ship Structure Committee being carried out at several laboratories should be studied before undertaking further work in this field.

3. The studies at Rensselaer Polytechnic Institute and Massachusetts Institute of Technology, as well as some of the aspects of the work at Lehigh University and Battelle Memorial Institute, have been interesting in determining the effect of microstructures on transition temperature. Further investigation of the effects of microstructures produced by the welding thermocycle would be useful if studied from the standpoint of the properties of the structures individually and in the aggregate. An exhaustive study of the role of strain aging in the welding of steel is needed. Preliminary work has been carried out by the University of California.

4. We need to know more about the effect of inclusions and alloy segregation, of cooling rates in the ingot phase, heating time in the slab and rolling procedure on the cracking tendency of weld joints. Although the role of carbon is pretty well established, active individual

elements, and elements in popular combinations, have not been fully investigated. Most welding engineers strive for crack-free structures and although much work has been carried out at Lehigh University and Battelle Memorial Institute in this field, many additional related investigations are in order.

5. Further investigation is needed of the role of gases such as hydrogen and nitrogen as well as the effect of residual or tramp alloys in steels on cracking and embrittlement of welds. Any such study would require the re-evaluation of the type of test program which might be used.

6. It would be desirable to prepare a quantitative evaluation of the effect of type of electrode coating on the cracking tendency. This might include a valuation of the performance of slag-shielded and gas-shielded electrodes on the soundness and quality of weld deposits. Little work has been reported relating to the metallurgical reactions between welding slags and molten weld metal.

7. The effect of restraint on cracking tendency has been repeatedly pointed out. Further investigation would be desirable in quantitatively evaluating the effective restraint in one specimen as well as various welded structures. It would be highly beneficial to the investigators in this field if it were possible to quantitatively evaluate restraint. Such an evaluation should provide a reference for correlating the various test pieces and data which have been obtained using various specimens and testing procedures.

8. There have been numerous questions raised regarding the effect of the so-called stress-relief treatment of welded structures. It would be well to investigate these effects in order to have a more fundamental basis for controlling the relief of shrinkage and locked-up stress in welded structures. The question has been raised as to whether furnace stress relieving of plates after they are formed, followed by preheating ahead of welding, is practically as effective as furnace stress relieving of the entire finished structure.

9. Another problem which is closely related to that of stress relief is that of using preheat in structures which normally are not suitable for furnace stress-relief treatment. Questions have been asked whether preheat and stress relief are supplementary or complementary. As additional information becomes available, it appears that the use of preheat has effects which are more extensive than would be indicated simply by the change in cooling rate in the welding zone.

10. It would be desirable to investigate the relationship of the stability for machining of welded structures which have been furnace stress relieved, fabricated with the use of preheat or fully annealed by heat treatment.

11. Recent studies by the American Bureau of Shipping have led to improved methods of quantitatively measuring the effects of peening. Further studies should be aimed at the evaluation of the effect of peening as far as the cracking tendency, notch sensitivity, dimensional stability, as well as the reduction of distortion.

12. Recent investigation at the University of California has pointed out the effects of cooling rate at relatively low temperatures. This work should be continued in order to determine whether such an effect might apply to welded structures.

13. It would be well to investigate the mechanical properties of the deposited metal using various types of electrodes over a wide range of testing temperatures. This study should be aimed at detecting brittle structure at both high and low temperatures.

14. Many difficulties have been encountered in the welding of low-quality steels containing segregation and laminations. These effects may be traced to gas content or melting and rolling practice. An example of this type of problem

would be that of investigating the nature and cause of porosity, particularly at starts and stops, on 4-6% chromium-molybdenum steel welded with mineral and lime ferritic-coated electrodes.

15. Other investigations aimed at the improvement of the welding of particular grades of steel would be desirable. *Example:* Additional work would be useful in studying weldability of cast steels with their generally higher silicon.

16. Further correlation is needed on the welding of heat-resistant materials for gas turbines and jet engines. Such a program should include a study of the efficiency of different welding methods on the properties of the materials involved in these parts for service at elevated temperatures.

17. Little effort has been reported on the over-all effect of composition on the performance of welded structures. Much of the original work at Battelle related to the effect of carbon and manganese. Preliminary work has shown that carbon is probably the most potent element in reducing the weldability of a steel.

18. A quantitative investigation of the recovery of various elements in arc welding would be informative. This should include welding processes other than with coated electrodes and should be aimed at improving the transfer and recovery of some of the materials such as titanium.

### (*B*) *Welding of Dissimilar Metals*

1. There is a lack of basic information in the welding of many of the nonferrous metals. This lack of basic information is even more acute in the welding of dissimilar metals. Little quantitative information is available concerning the nature and mechanism of alloy diffusion or pickup and dilution. These problems pertain especially to the resistance welding of dissimilar metals such as:

(*a*) Dissimilar ferrous metals.
(*b*) Dissimilar nonferrous metals.
(*c*) Dissimilar ferrous to nonferrous metals.

A considerable amount of work on spot welding of unlike aluminum alloys has been reported by Rensselaer Polytechnic Institute. Other problems remain such as the spot welding of stainless steel to low plain carbon or hardenable alloy steels.

2. There is also a lack of basic information in connection with (1) the arc welding of clad materials, (2) the arc welding of dissimilar metals and (3) the arc welding facing operations.

3. In addition to the above, information is needed on joints between dissimilar metals as to:

(*a*) Thermal expansion characteristics.
(*b*) Mechanical properties.
(*c*) Effect of elevated temperature on alloy diffusion and the effect of the diffusion on the properties of the joints. This is important in high temperature applications of clad materials, hard facings, etc.

4. Brazing and soldering involve the same general problem as that of joining dissimilar metals. There is also, however, the specific problem of surface tension, more commonly called the tinning property of solders, which requires a fundamental approach. A method is required to measure the tinning properties of various brazing and soldering materials.

## III. MECHANICAL PROPERTIES AND TESTING

Many of the problems raised under the heading of "Metallurgy" cannot be properly solved unless the *stress* and *strain* characteristics are correctly accounted for. Further, determination of actual mechanical characteristics of material fabricated into a structure and the change of these characteristics produced by welding are not always shown up by usual tests and testing equipment. There-

fore, welding has a large stake in the field of mechanical engineering and testing. Of basic importance for welding is what has been defined as "The Weld Stress Problem."* This is of major interest in the welding of steel, but the problem extends to all materials and involves both metallurgical and mechanical fields of research. The following covers only the mechanical aspects.

It is axiomatic that failure of a structure must be preceded by plastic flow. In some cases this plastic flow is of such a small amount as to be almost negligible, and in extreme cases, such as failure of a glass jar at ordinary temperatures, no measurable deformation may take place. However, even in this case there is an attempt to plastically deform. The state of stress influences the conditions under which plastic flow can take place. For example, theoretically, balanced triaxial stresses would cause carbon steel to act as a glass jar, i.e., no measurable deformation would take place before failure.

### (*A*) *State of Stress*

From the host of information which is beginning to accumulate as a result of research, evidence seems to emerge that states of stress which are not higher than biaxial do not alter appreciably the initiation of plastic flow as compared to the uniaxial tension test. This statement is valid for the applied as well as residual state of stress. The influence of notches and metals dissimilarity is under investigation, but if conditions are limited to the surface, the situation does not appear to be much affected by these two factors. The real problem is, therefore, what happens below the surface. This problem is equivalent to that of a triaxial state of stress, for obviously no triaxial state of stress can exist at the surface.

It is obvious that one of the most important and difficult problems confronting the research investigator is to determine what basic laws govern the elastic and plastic deformation of metals under various conditions. Additional information is badly needed, especially on the following topics:

1. Quantitative data on how much a steel of known conventionally determined physical properties at different temperatures—strength, yield point, ductility—will deform plastically under specific conditions of constraint and speed, intensity and cycles of loading.

2. Determination of the plastic and elastic interaction between base and weld metals having different mechanical characteristics, yield point, ultimate tensile strength and elongation under various external loadings.

### (*B*) *Rate of Straining*

The influence of temperature and rate of strain upon the plastic behavior of steels is of fundamental importance. Considerable work has been done along these lines. However, much more data are needed before it will be possible to apply findings to ordinary steel structures. There is evidence that in ferritic steel the total amount of strain before failure is influenced by two factors—temperature and rate of strain. This information should be extended.

### (*C*) *Size Effect (Rigidity)*

Evidence begins to accumulate slowly that the tendency toward brittle fracture increases as the thickness becomes greater. The word "rigidity" has been used frequently to describe this behavior, and plasticity experts would think probably of the word "triaxiality." Actually neither of these terms seems to be any better than the other, as the true situation is probably far more complex. How-

* "The Weld Stress Problem," THE WELDING JOURNAL, 24 (6), Research Supplement, 313-s to 319-s (1945).

ever, if it were possible to express one situation in terms of another, say rigidity in terms of plate thickness, or the latter in terms of triaxiality, an important step forward would have been made.

### (*D*) *Residual Stress*

In order for residual stress to contribute to the failure of a structure it would be necessary for plastic flow to be inhibited to the point that such residual stresses would not be relieved by local plastic deformation. Enough work has been done to show that only under very specialized conditions would it be possible for residual stresses to thus contribute to failure. The important question is, in actual failures do such conditions exist? The fact that several ships have failed under conditions where the imposed loads were very low would indicate the possibility of harmful effects due to residual stresses. The problems therefore are: (1) to determine if the conditions necessary for residual stresses to contribute to failure can actually exist; (2) to quantitatively evaluate the effects, both beneficial and otherwise, of residual tensile and compressive stresses, especially in welded structures; and (3) to determine the actual effect, both on metallurgical structures and on the state of stress of the various stress-relieving processes, including overstressing by hydraulic loading, thermal stress relief, low-temperature stress relief and peening. Some of this work is now being done at various laboratories. The Welding Research Council is to be contacted for further information.

### (*E*) *Mechanical Properties of Welded Joints*

The study of the mechanical properties of welded joints has provided important information to the users of welding processes and represents an outstanding contribution to the development of these processes. Fundamental data are still needed in many fields, and the determination of these data can become a gratifying subject for many graduate and undergraduate thesis investigations. The following problems should be considered.

*1. Fatigue Studies.* While fatigue is at present a problem only under certain highly specialized cases, if higher design stresses are more widely used, the problem of fatigue becomes more important. The endurance limit of steel is generally a function of ultimate tensile strength. However, there are several proposed methods of increasing fatigue resistance, and these should be studied. Also, fatigue effect on fabricated structures should be more thoroughly investigated. For example, many beams are fabricated by cutting and rewelding standard structural shapes. Fatigue effects on these are as yet unknown. Studies of fatigue in the plastic range are only limited in extent and should be broadened.

*2. Test Methods.* It is recognized that the conventional physical tests do not accurately reflect the properties of material fabricated into structures. A whole series of weldability tests which attempt to take into account the structural factors have been proposed. None has been widely adopted. A rational test method is badly needed which will enable the behavior of structures to be predicted on the basis of small-scale tests.

*3. Theory.* Various theories covering the strength of materials have been applied to welded structures. So far, it has been impossible to apply any generalized theory, making necessary lengthy and involved calculations. The various strength theories which have been proposed should be critically evaluated, especially as applied to structures with dissimilar properties of weld and base metal.

*4. Specific Problems.* There are a number of specific problems which have been referred to the Welding Research Council. These are listed below. In

many cases, the broader problems referred to above would automatically involve solution of these individual questions:

(*a*) Determination of the magnitude and distribution of stress in welded joints, particularly in pipe.

(*b*) It is important to determine to what extent plastic straining during the hydrostatic pressure test can be relied upon to impart final shape to a pressure vessel without impairing the mechanical characteristics of the material. This problem is of practical interest, since it has been observed that the metal near the junction circle of the knuckle and crown of a conventional basket (dished or torispherical) pressure vessel head frequently deforms plastically under the prescribed hydrostatic test. Similarly, depending upon the apex angle and the ratio of thickness to shell radius, the joint between the conical head and the cylindrical shell of a pressure vessel deforms much or little under the hydrostatic pressure test. The change of properties produced by the above operation should be studied by one of the methods worked out in connection with the study of weldability, outlined previously under Section II—Metallurgy. It is hoped that a carefully planned and executed test and analytical program will provide a reliable basis for design.

(*c*) The most careful designing of the shell of a pressure vessel may be completely nullified by poorly designed supports. Investigation is desirable as to the proper method of design for saddle, ring and lung supports for horizontal cylindrical vessels; and skirt, bracket and column supports for both spheres and vertical cylinders.

(*d*) Investigation is needed of reinforced manhole openings where the manhole consists of a forged ring butt welded into the shell plate and the manhole cover is attached by stud bolts in the ring.

(*e*) Determination of the concentration of stresses and development of suitable maximum design stresses in vertical vessels having semi-elliptical head and supported on skirts that are attached to the knuckle of the head.

(*f*) The same as above where the vertical vessel has a conical or toriconical head.

(*g*) Correlation of tensile properties of steel plate in a direction at 90° to the plane of the plate, with the permissible design stress of lap or fillet weld joints subjected to tensile loads in the same direction. This is of interest in connection with proper evaluation of fillet and lap weld joints in applications where stresses in the direction described above are involved, such as in certain types of nozzle, head, staybolt and tube sheet connections to pressure vessels, and in some structural and similar joints.

(*h*) Thermal transient stresses in pressure vessels submitted to sudden changes of temperature.

(*i*) Application of sonics and supersonics to nondestructive testing of weldments.

(*j*) Although numerous proposals have been advanced for the nondestructive testing of flash and spot welds, there is a place for more simple and reliable methods, if these can be developed.

## IV. STRUCTURAL STUDIES

Most of the pioneering work in welding has started in the structural field. This work has been concerned with welded joints and welded connections as applied to existing types of structure, and has resulted in a substantial improvement and economy of the structural design. In some cases, however, the results were less gratifying especially where the increased rigidity of welded structures had been obtained by increasing the thickness or accumulation

of the weld deposit. The fundamental problem of local rigidity has been discussed previously in Section III under the heading of Mechanical Properties and Testing. Whatever solution is accepted for this fundamental problem, adequate methods of design must be provided. Briefly stated, the problem is to design a structure in which greater load-carrying capacity and greater stability can be achieved without increasing locally the thickness of elements or accumulating a greater amount of weld. This problem can be studied by one of the following means:

1. Model studies on frame and plate-like structures.
2. Design of new types of section for welding.
3. Testing of full-scale structures.

In addition to this fundamental problem, many immediate problems await solution, such as:

4. Transfer of stress at end of partial-length cover plates.

5. Design of spot-welded joints. This problem involves the determination of proper size, spacing and distribution of welded spots for the purpose of achieving maximum efficiency in static and fatigue loading.

6. Influence of distortion produced by welding on the stability of flanges and webs in large plate girders.

7. Stress distribution in full-scale welded structures. Experimental and mathematical analysis of stress distribution in beam and column connections and in built-up girders should be made in order to deduce reliable design formulas.

8. Influence of residual stress on the stress distribution in statically indeterminate structures. More specifically, it is important to determine whether the early plastic flow resulting from the presence of residual stresses is beneficial in redistributing the effect of overloading.

9. Increased knowledge is needed of shrinkage stresses from the point of view of controlling, minimizing and correcting distortion.

10. Significance of fatigue in weld design with the idea of improving the strength of structural members when subjected to cyclic loading. These improvements can be brought about by more favorable geometry or by more favorable metallurgical conditions at the point of initiation of fatigue failures.

11. The reliability of engineering calculations appertaining to structural strength with the idea of avoiding brittle fractures.

12. A study of the relative effects on weld quality (particularly notch sensitivity) of weld metal stronger than the parent plate, weld metal weaker than the parent plate and weld metal of substantially the same strength as the parent plate.

13. Most desirable methods of welding reinforcing bars used in reinforced concrete.

## V. RESISTANCE WELDING

Resistance welding embraces the processes of spot welding, seam, projection, flash, upset and percussive welding. A detailed description of each of these processes and the equipment necessary thereto is contained in the *Welding Handbook* published by the American Welding Society.

The research problems are rather arbitrarily divided into: (*A*) Electrical and Physical Characteristics, (*B*) Metallurgical Effects, (*C*) Physical Properties and Tests. However, there is considerable overlapping among these groups.

*(A) Electrical and Physical Characteristics*

1. Determine the relationship between electrical contact resistance and the current, pressure, temperature and surface preparation of the metal welded. An additional phase of this problem involves the thermal contact resistance and the same variables. Another problem would be to investigate the possibility of the application of spreading resistance techniques to spot welding of copper.

Researchers are referred to technical reports published by Rensselaer Polytechnic Institute and Johns Hopkins University on this subject.

2. In flash welding study the relationship of the variables flashing speed, current, current cutoff and pressure. Thorough instrumentation is required, including a recording watt meter and recording oscillograph.

3. An investigation of electrical resistance brazing including current density, pressure, temperature and heating time for specific brazed areas, comparing results with conventional furnace heating. Some limitations are encountered in making large area joints by furnace brazing, and this tendency should be studied in resistance brazing.

4. Study the effect of postheating on the fatigue strength of spot welds. Postheating is one method that holds possibility of increasing the comparatively low fatigue strength of spot welding joints.

5. Determine the effect of the shape of the abutting ends of upset butt-welded rods upon the physical properties of the joint. Considerable change in properties has been found with different end preparations, particularly on rods containing higher carbon contents up to about 0.65%. Different preparations could include flat, chisel point or cone points.

6. Seam welding steel. The speed with which a seam weld can be made is proportional to the frequency of the a.-c. power supply. Each wave produces a weld nugget and above certain speeds unwelded areas appear between these nuggets, resulting in lack of pressure tightness. It may be possible to devise other electrical systems without this defect.

*(B) Metallurgical Effects*

1. Investigate the metallurgical effects of welding dissimilar metals. Work with Monel, nickel, Inconel and chrome nickel stainless grades should be considered.

2. Spot welding of copper. This process depends on proper electrodes which will not deteriorate in contact with the copper workpieces. It may be necessary to generate additional heat within the electrodes so that the fusion temperature may be reached in spite of the high thermal conductivity of the copper workpiece.

3. Spot welding of silicon bronze, silicon brass and red and yellow brass to determine optimum welding conditions. Contact resistance must be carefully measured and the application of electron defraction equipment might be useful.

4. A study of the effect of welding conditions upon the mechanical properties and corrosion resistance of spot-welded aluminum alloys.

5. Investigation of the effects of spot welding on steels coated with low melting point metal, e.g., galvanized steel, tin plate, terne plate, gilding metal.

6. Effect of metallurgical quality (deoxidation, grain size, surface finish) on the spot weldability of steel. Again surface contact resistance is of prime importance.

7. Basic studies of the properties of resistance-welded titanium.

8. Micro investigation of the fusion line of flash and upset butt-welded joints for decarburization, or other variations

in structure produced by variations in the welding conditions. Anomalies in properties of these welded joints have been ascribed to local variations in the structure at the fusion line.

*(C) Physical Properties and Tests*

1. Spot welding. Valuation of the effects of residual stress in spot-welded assemblies. Stress concentrations of a severe order exist in spot welds and have an influence on the properties.

2. Development of nondestructive tests and evaluation methods for resistance welds.

3. Effect of fiber distortion in flash and upset butt welding. A study could include a cold-rolled or drawn material with pronounced longitudinally oriented structures plus the same material in the normalized condition.

# TURBINE RESEARCH AND DEVELOPMENT

ACKNOWLEDGMENT

This paper describes the British Pametrada (Parsons and Marine Engineering Turbine Research and Development Association) Progress Report for 1950. The article was published in the July, 1951, issue of "The Shipbuilder and Marine Engine-Builder."

The Progress Report of the Parsons and Marine Engineering Turbine Research and Development Association (Pametrada) for 1950 contains much interesting information in regard to the work carried out during the year by the design and research departments of the organization. The volume of work handled by the design department had continued to increase steadily, both in the development of new constructional features and in the preparation of designs of turbines and gearing for new vessels.

## THE DESIGN DEPARTMENT

During 1950, more than two-thirds of the total horsepower of geared-turbine machinery put into commission by member firms represented designs prepared by the design department. A proportion of these installations followed the practice established before Pametrada had commenced activities, but there was a noticeable increase in the number of installations incorporating Pametrada designs.

The year had been marked by great activity in the construction of large oil-tank vessels. Three, each of 28,000 tons deadweight, had been completed for the Anglo-Saxon Petroleum Co., Ltd., *viz.*, the *Velutina* (built by Messrs. Swan, Hunter & Wigham Richardson, Ltd., Wallsend, and engined by the Wallsend Slipway and Engineering Co., Ltd), the *Verena* (built and engined by Messrs. Harland & Wolff, Ltd., Belfast) and the *Volsella* (built and engined by Messrs. Cammell Laird and Co., Ltd., Birkenhead). A fourth vessel of the class would be completed during 1951.

The continued predominance of large tank ships was evident in the new designs being prepared by Pametrada. A series of 28,000-ton vessels for the British Tanker Co., Ltd., was nearing completion, the first of the group—the *British Adventure*—having been launched in December, 1950, by Messrs. Vickers-Armstrongs, Ltd., Barrow-in-Furness. Basis plans were almost complete for the machinery of a large tank vessel for the Standard Oil Company; the installation incorporates turbines of Pametrada design and comprises an all-impulse h.-p. ahead turbine carrying an overhung h.-p. astern turbine, and a reaction l.-p. turbine incorporating an astern element. The associated gearing

would be of the double-reduction articulated type and the steam conditions at the superheater outlet are as follows: Pressure, 850 lb. per sq. in. (gauge); and temperature, 850 deg. F.

In a number of other large tank ships under construction, the propelling machinery was similar to that installed in the Anglo-Saxon 28,000-ton ships.

Interesting designs prepared during 1950 had included turbine and gearing basis plans (to the order of Messrs. Vickers-Armstrongs Ltd.) for the propelling machinery of a destroyer for the Venezuelan Government; designs of the propelling machinery for very large tank ships, of up to 42,000 tons deadweight; and a number of special designs for cross-channel and naval vessels.

## STEAM-TURBINE DESIGN DEVELOPMENTS

Among technical developments in regard to turbine components, probably the most important was that relating to methods of manufacturing the diaphragms and blading in impulse turbines. This development provides for the assembly of separate blades and packers cut from rolled strip and brazed together in short groups. Hydraulic-pressure tests in a diaphragm embodying this method of construction had shown that its strength and stiffness were fully up to expectations; in fact, the observed deflection was less than one-quarter of that of the present standard all-machined type.

In view of these satisfactory results, it had been decided to adopt this design in the turbines of four recently-ordered vessels, the steam conditions at the superheater outlet being: Pressure, 650 lb. per sq. in.; and temperature, 850 deg. F.

Machinery for making the blade and packer strips was being manufactured by Messrs. C. A. Parsons & Co., Ltd., Newcastle-on-Tyne. The section characteristics were selected after the wind-tunnel tests on these alternative designs. The form chosen, it is claimed, confers much greater latitude in the choice of section, in contrast to the all-machined type, where manufacturing considerations impose limitations on the type of section.

The constructional advantages offered by the segmental method of blade assembly had stimulated a detailed examination of all known methods for securing the blades, and it was hoped that it might be possible to evolve a fixing, suitable for segmental construction, from rolled strip and packer, and which retained the inherently high economy of axial length of the normal milled blade roots of tee or straddle form.

It was considered that a blade root having a strength somewhat inferior to the maximum obtainable with normal types would be suitable for practically all high-pressure blading, and for up to 90 per cent of the blading of low-pressure turbines of the impulse type.

It had not been found possible, however, to apply segmental construction to any known blade-root form without sacrificing axial length; and, though a satisfactory form had been evolved, it was found to be covered by a British patent recently issued to applicants who were not members of the Association. As an alternative to negotiating a manufacturing license, the search for alternative forms had been continued and had culminated in the development of what appeared to be a fundamentally new form of turbine-blade fixing, possessing all the required characteristics and, in addition, promising to be stronger than any known form of root, with the exception of the almost prohibitively expensive side-entry type. The new form was being thoroughly tested, and it was confidently expected that, in a comparatively short time, this type of root would supersede all others in impulse turbines constructed to Pámetrada design.

## OPERATIONAL PERFORMANCE

The behavior of turbines built to Pametrada designs and installed in new vessels had been studied under trial conditions. The large number of such turbines now in service had so far proved remarkably free from trouble.

There had been some further instances of scuffing in reduction gearing (referred to in last year's report). While the full explanation of these difficulties remained to be found, it appeared that increased tip relief would, at least, ameliorate the condition, and, if sufficiently far-reaching, might effect a complete cure. The extent to which the full depth of tooth remained available for load-carrying when the tip was relieved by amounts up to as much as 0.005 in. was still conjectural; at present, excessive tip relief was regarded as a palliative rather than as a necessary feature of involute-tooth gearing.

Two investigations of machinery troubles had been carried out during the year under review. The first concerned a new set of double-reduction gearing, in which peculiar "knocking" was heard during the shop trials. This was finally traced to a fault in the hobbing machine on which the gears had been cut. After rectification of the fault, the gears were re-cut on the same machine and were found to be entirely satisfactory.

The second investigation concerned a series of large tank vessels, in which the severity of the one-node torsional critical speed had proved somewhat greater than had been anticipated. This was primarily due to the fact that the "critical" occurred 30 per cent higher in the power range than had been expected. A new form of torsiograph was developed for this investigation. Electrical in character, the instrument has the advantage that it can record vibrations at four different points simultaneously. The pick-up element is driven by the shaft under investigation. It is a comparatively simple and inexpensive matter to fit the units at a large number of points in the system to be investigated. The indications of any four of the elements can be recorded simultaneously, and, in a matter of seconds, any other set of four elements may be substituted by electrical switching.

The new torsiograph was devised by the design department of the Association and developed and constructed by the research department. The system investigated comprised three turbines, driving the output shaft through articulated double-reduction gearing. The one-node critical occurred at approximately 60 per cent of full speed in all the vessels investigated. At this speed, the torque developed in the l.-p. turbine was very small, and the opinion was formed that, in these conditions, the l.-p. gear train was virtually idling. In such circumstances, the turbine inertia would not have its anticipated effect on the system as a whole; and a calculation based upon this assumption gave a theoretical critical speed in close agreement with the observed value. The verification of the theory would, however, entail further investigation.

## REDUCTION-GEARING RESEARCH

The theoretical examination of improved forms of reduction gearing had been actively pursued during the year, especial attention having been paid to the development of gearboxes capable of driving either ahead or astern, at will, and having double epicyclic trains in which rotation of either of the two annulus members could be prevented by hydraulic brakes. With one brake in

use, the gear drives the propeller shaft in the ahead direction; with the other brake in use, the direction of rotation is reversed and, at the same time, the reduction ratio is altered to suit astern conditions. Though some time would elapse before such gears had been developed to a stage at which they might be installed in an ocean-going vessel, efforts in this direction would be well repaid in the simplification of turbine design.

### STEAM-TURBINE TESTING AND RESEARCH

Among the major activities of the research department had been the full-scale testing of steam-turbine machinery for the Admiralty. The plant for carrying out these tests had been completely assembled, and the methods of calibration and control adopted ensured that the tests could be repeated within an accuracy tolerance of ±¼ per cent. These tests, it was claimed, were the most extensive ever carried out ashore on marine turbine machinery.

In continuation of the tests of machinery for the *Daring*-class destroyers, trials had been conducted on the *Daring II.* machinery, which is identical with the *Daring I.* installation, with the exception that it incorporates an impulse h.-p. turbine, instead of the impulse-reaction h.-p. turbine of the *Daring I.* installation.

The steam-flow path of the *Daring II.* unit was designed by the British Thomson-Houston Co., Ltd., Rugby; the detailed drawings were produced by Pametrada; and the machinery was constructed by Messrs. John Brown & Co., Ltd., Clydebank.

The duration of these main-machinery trials had amounted to 286 hours. The consumption trials had been performed in one continuous run.

The erection of the *Daring III.* all-impulse machinery (for trials) was begun in July, 1950; the tests began in mid-November and were still in progress at the end of the year.

Measurements of the pressure drop in steam pipes were made with the aid of a special mercury manometer, in which the mercury level in a steel tube is ascertained by means of gamma rays and an ionization screen. In the *Daring II.* trials, this device was employed to measure the pressure drop across the first group of nozzle-control valves.

### CONDENSER DEVELOPMENTS

Measurements of the heat transfer in condensers had been made on the occasion of the *Daring I.* trials, and a further investigation was made during the *Daring II.* trials, in order to establish heat-transfer coefficients in individual condenser tubes. The results, however, were not conclusive; overall heat-transfer measurements showed the condenser to be functioning inefficiently, and subsequent cleaning of the condenser tubes resulted in a large improvement. Owing to difficulties in instrumentation, it had not been possible to obtain reliable pressure-drop measurements on the steam side of the condenser. In the *Daring III.* trials, therefore, the vacuum-gauge pipes were modified, and consistent readings were now being obtained. No further attempt had been made to determine the heat-transfer characteristics of individual condenser tubes; research on this problem was confined to the experimental condenser.

Condenser research being carried out included two items. The first involved a medium-sized experimental condenser, in which an investigation was to be made of the heat-transfer rate, the distribution of the effectiveness of the tubes, the effect of circulating-water

speeds and conditions of flow on the steam side. The condenser was being tubed by the Wallsend Slipway & Engineering Co., Ltd. The ancillary equipment was in course of manufacture at the end of the period under review.

The second item comprised similar tests on a number of small condenser elements developed by Professor Cave-Brown-Cave. These elements have secondary surface on the water side, and the steam-side flow paths are tapered with the object of maintaining the velocity of the vapor over the surfaces as condensation takes place.

*Measuring Condenser-water Temperature.* The measurement of condenser-water temperature had been found somewhat unreliable in earlier trials, and for the *Daring III.* trials a new method was employed. The technique was based on the use of the Thermistor—a device recently developed by the Standard Telephones and Cables, Ltd., London, and which is virtually an electrical resistance with a very high negative temperature coefficient.

For the condenser trials, 12 Thermistors were employed—two in the inlet and a grid of 10 in the outlet. Each Thermistor was encased in a small capsule made from condenser tubing, filled with transformer oil and sealed. The 12 measuring heads were automatically selected in turn, the temperature of each being displayed for 10 seconds. The instrument, which comprises a Wheatstone-bridge arrangement, with a large milliammeter to measure the unbalance in the bridge caused by the Thermistor temperature characteristic, gives readings proportional to the temperature of the Thermistor to which it is connected. Each Thermistor has been calibrated with the instrument and, in the range between 32 and 120 deg. F., an accuracy of $\pm 1/4$ deg. F. is obtained.

## TEMPERATURE AND DISTORTION IN STEAM TURBINES

Among the various experimental investigations carried out on steam turbines during the year, those relating to temperature distribution and thermal expansion were particularly noteworthy. During the *Daring II.* trials, observations of the temperature distribution in the l.-p. turbine casing during astern running were made with the aid of an improved type of thermocouple head. In order to measure the relative movement between rotor and casing at the after end of the turbines, air pressurized gauges were employed. The observations confirmed that the gashed rotor of the *Daring II.* machinery expanded and contracted more rapidly than the solid rotor of the *Daring I.* machinery, due to the circumstance that the thermal capacity of the gashed rotor was less than that of the turbine casing.

In order to ascertain the temperature in the rotor bore, thermocouples were employed in the rotor of the *Daring II.* turbine; in the *Daring III.* trials, an improved version of the apparatus has so far given excellent results.

In regard to the measurement of turbine distortion, previous trials had shown that optical methods of measurement might give inconsistent results under testhouse conditions. Mechanical means were therefore devised, and satisfactory results were obtained.

For the purposes of turbine-blade research, an interesting test rig had been devised. The rig was in the form of a single-stage impulse turbine in which the nozzles rotate, while the blades remain stationary, so that blade vibration may be examined more thoroughly.

At the end of the year under review, plans had been made to conduct turbine water-drainage experiments with the object of determining the quantity of water which might be removed from the steam towards the end of its expansion

in the turbine, and the effect of varying degrees of moisture removal on turbine efficiency. It was also intended to examine the effect of moisture on the erosion of the final blades. Suitable water-catchment devices were being developed, and these would eventually be incorporated in a new inner casing to be ordered for the Pametrada "Utility" turbine.

## GAS-TURBINE RESEARCH

A number of difficulties had arisen in the operation of the experimental 3500-S.H.P. marine gas turbine. Particularly troublesome was the behavior of the h.-p. and l.-p. compressors, which exhibited surging at much greater mass-flow rates than had been expected. Fuel was first burned in the combustion chambers of the set on the 18th and 19th April; for some 10 days, efforts were made to bring the set to the self-running condition, but were stopped by the occurrence of gland distortion in the h.-p. turbine. After modification of the gland sleeves, with a view to preventing this distortion, running was resumed on the 18th and 19th May, but movement of the h.-p. turbine casing caused gland and blade "rubs." Moreover, self-running was impossible, owing to the early occurrence of surging in the compressors.

It was therefore decided to conduct further basic investigations into the aerodynamic and mechanical behavior of the compressors before again testing the unit as a whole.

During the ensuing months, considerable trouble was experienced as a result of blade rubbing in the h.-p. turbine, and various measures were taken in order to cure this defect. Wind-tunnel tests on models of the inlet ducting and the compressor-inlet belts revealed the need for corner cascades in the ducting and certain other measures.

All modifications were completed by the middle of August, but it was then found that the fixed and moving blades of the h.-p. compressor rotor were fouling each other. The fault was rectified and the re-erection of the compressors was completed at the beginning of September. It was found that the compressor characteristics had been much improved when running the compressor up to a speed of 2780 r.p.m. by means of the starting motor. Actual running of the unit began on the 20th October and the h.-p. set reached the self-running condition at about 4300 r.p.m. with an h.-p. turbine-inlet temperature of about 750 deg. F. Despite the improved performance, however, surging still occurred at too large a mass flow. Further alterations achieved no improvement in this respect; it was therefore decided to reduce the blade height (and thus the flow area) throughout the l.-p. compressor, and this work was still in hand at the end of the period under review.

*Experimental Compressor.* In view of the difficulties experienced with the compressor for the 3500-S.H.P. marine gas-turbine plant, it is of interest to note the reference in the report to an experimental axial-flow compressor, built by Messrs. Cammell Laird & Co., Ltd., for the purpose of obtaining design data. The trials of this compressor were to be supplemented by tests on blading in cascade.

*Combustion Chambers.* Considerable experience had been gained in the operation of the combustion chambers of the 3500-S.H.P. gas turbine. The chamber had so far given no trouble, and the flame length appeared to be even shorter than expected. The report pointed out that the chamber had yet to function under more severe conditions, and there were indications that some parts of the flame tube might be overheated.

A small combustion chamber, with improved air cooling, was under construction for research purposes, and a miniature combustion rig for studying

ash-fouling problems had undergone preliminary tests. The effect of ash on turbine blades was receiving attention, and much work had been carried out on the destructive effect of vanadium-bearing ash on gas-turbine steels. An investigation into the potentialities of refractory turbine blades was being pursued, in conjunction with the Morgan Crucible Co., Ltd.

## POWER-TRANSMISSION DEVELOPMENTS

In the section dealing with power transmission, brief references are made to various investigations. A back-to-back test was being conducted on the Swiss-made Maag gearing, intended for H.M.S. *Diana*. These two-cylinder double-reduction locked gear trains, which are of the single-helical type, are air-hardened and ground.

In a back-to-back test, a 4000-H.P. set of hobbed gears, without helix correction, had been run to destruction. These trials were followed by tests on similar gearing, in which the helices were corrected for torsion and flexure, and it was found possible to operate this set with the substantial overload of 225 percent, in excess of the normal rating, without sign of failure. This condition represented the limit of the torque loader employed, and it was intended to make the loader suitable for the application of still higher torques.

Testing and development work had proceeded in connection with hydraulic reversing mechanisms, incorporating a coupling of modified Vulcan type for ahead running and two alternative types of astern converter designed by the Association. The units were suitable for use with the 3500-S.H.P. gas turbine, but such mechanisms were applicable to both steam and gas turbines.

The development of electromagnetic torque meters had met with a number of difficulties which were being gradually overcome. A preliminary design had been prepared for a hydraulic torque meter, based on a maximum torque of 5000 lb.-ft. at a maximum speed of 9000 r.p.m.

A precision r.p.m. indicator, to be employed in conjunction with the experimental compressor mentioned in the foregoing, was also being developed.

# PURIFICATION OF DIESEL-ENGINE FUELS IN RELATION TO CYLINDER-LINER WEAR

## With Special Reference to the Employment of Boiler Oil in Motor Ships

ACKNOWLEDGMENT

The May, 1951, issue of "The British Motor Ship" contained this article by JOHN LAMB.

That the main engines, and in many cases the auxiliary oil engines, of some hundreds of motor ships have been equipped to burn boiler fuel since the writer's papers on this subject were presented before the Institute of Marine Engineers in December, 1947, and April, 1950, demonstrates that shipowners and their technical advisers were favorably impressed by the results previously obtained in the *Auricula* and other motor ships of the Anglo-Saxon Petroleum Co.'s tanker fleet.

At the present time, 35 Anglo-Saxon tankers of round about 12,000 tons d.w., propelled by Werkspoor, B. and W., and M.A.N.-type engines, have been equipped and are operating with entire satisfaction on ordinary commercial grades of fuel obtained from world-wide bunkering ports. The viscosity of the fuels shipped varies from 100 secs. to 3500 secs. Redwood No. 1 at 100 degrees F., and the only alteration necessary is to fit a different type of fuel-valve nozzle when the viscosity of the fuel is between 1500 and 3500 secs.

### OPERATING ADVANTAGES OF BOILER OIL

Experience totaling 38 ship-years with this large number of tankers proves that the engines require no more attention than when operating on Diesel fuel, and that the wear rates of cylinder liners and piston rings, particulars of which will be given, are no greater when burning the cheaper grades of fuel. Moreover, the length of time that such parts as exhaust valves will operate without attention is found to be greatly increased, while the less "searching" property of the viscous fuels has advantages. Because of this, and the fact that engines run more smoothly when burning high-viscosity fuels, it is not uncommon for ships' engineers to ask, when being reappointed after furlough, for a motor ship which is operating on such fuel.

Of the vast majority of motor ships operating on boiler fuels treated in the

manner recommended in the two papers referred to earlier, the desired good results are being obtained, but a few instances have come to the writer's notice where cylinder-liner and piston-ring wear rates are greater than, it is alleged, would have been the case had the engines operated on the most costly, heavier and less viscous Diesel fuel.

Upon investigation it is generally found that either the fuel is not being treated or the engine is not being operated in the manner necessary when burning boiler fuels. In some cases it is found that purifying and injection temperatures are not being adhered to, whilst in others the maximum quantity of injurious matter in the fuel is not being extracted because the important practice of reducing the through-put of the centrifugal separators is not being followed. The importance of subjecting the fuel to centrifugal force for a time sufficiently long to extract the whole of the insoluble ash cannot be emphasized too strongly. It may be that some makers of these machines express the view that it is unnecessary to reduce the throughput of their particular products, and as the writer has not had experience with all makes of centrifugal separators he cannot dispute this statement; but as regards the machines with which he has had experience, there is no doubt whatever that the rated capacity must be reduced when purifying high-viscosity fuels for Diesel engines. Those responsible for the operation of motor ships on the cheaper grades of fuel are, therefore, advised to satisfy themselves that such claims can be substantiated before they are accepted.

Apart from this and the necessity to ensure the equipment installed being adequate for the purpose, the results obtained are in the hands of the ships' engineer officers, and in view of this and the fact that the junior members of ships' engine-room staffs may not be fully appreciative of the importance of adhering to temperatures and rates of throughput, it may be helpful to set down the fundamentals of fuel purification and make suggestions regarding variations in procedure which may become necessary with certain grades of fuel.

## INJURIOUS MATTER IN VISCOUS FUELS

Insoluble ash consists chiefly of particles of earthy matter, rust, etc., picked up between leaving the oil refinery and reaching a ship's daily supply tank, and the particles vary considerably in size and weight. The larger and heavier particles settle out quite readily if the fuel is left undisturbed for a time, but the smaller particles in fine powdery form are so buoyant that they remain in suspension and can only be extracted by filtering, which is a slow process, or by centrifuging. As the division between the particles that settle out whenever the fuel is left undisturbed and the particles that do not is dependent upon the weight or gravity of the fuel, the reason why high-viscosity fuel, which as a rule, but not always, varies directly as the gravity, contains a greater proportion of insoluble ash, is understandable.

## EFFECT OF HEATING VISCOUS FUELS

Applying heat to fuel has the effect of increasing its bulk and reducing its weight per unit volume. Heat has relatively no such effect upon the particles of solid matter contained in the fuel, so that the effect of applying heat to such a mixture is to increase the difference between the weight of the liquid and that of an equal volume of solid matter. Raising the temperature of a quantity of fuel has the effect, therefore, of facilitating the separating of the liquid

and solid portions of the fuel, irrespective of whether the separation is effected by means of settling-out or centrifuging.

In practice it has been found that the most suitable temperature when centrifuging is 180 degrees F., and 100 degrees F. when settling-out. The reason why the settling-out temperature is relatively low is because the long time the fuel is usually subjected to this temperature is bound to have an adverse effect on the fuel.

When centrifuging the time is too short for detrimental changes of this nature to occur, and a temperature higher than 180 degrees F., could be adopted without ill-effect in the direction mentioned; but experiments have shown that, from the point of view of maximum extraction of objectionable matter, there is nothing to be gained by heating the fuel to a higher temperature.

The usual practice on board ship is to heat the fuel before it is taken from the storage tanks for purification. There is no objection to such a practice, since it reduces the heat to be applied in the heater just prior to the fuel entering the centrifugal separators. As, however, the heat will be applied to the storage tanks for a relatively long time, the temperature should not be allowed to exceed the temperature recommended for settling-out, namely, 100 degrees F.

## MATTER EXTRACTED BY CENTRIFUGAL SEPARATORS

The frequency with which the bowls of these centrifugal machines require to be emptied depends upon the quantity of solid matter and, to a certain extent, the composition of the fuel. The main purpose of centrifuging is to extract water and insoluble ash, which tend to be greater in quantity with high-viscosity fuels. It does not follow, however, that the higher the viscosity the more frequently will the separator bowls require to be emptied, because these machines can extract other constituents of petroleum fuels, as, for instance, wax. As waxy constituents of petroleum are good combustibles and readily burnt in Diesel engines, they should not, if it can be avoided, be extracted.

## THROUGHPUT OF CENTRIFUGAL SEPARATORS

As regards the extraction of the insoluble ash content, which is mainly responsible for the wear of cylinder liners and piston rings, the aim should be to extract the whole of this objectionable matter.

This has been found to be quite possible irrespective of the viscosity of the fuel *providing the fuel is subjected to centrifugal force long enough.* In other words, it is most important that the throughput of centrifugal separators should not be greater than that found necessary to extract the whole of the insoluble ash content. In the case of the separators which the author used, it was found that the desired results could be obtained only if the throughput was half the throughput of the machines. This rate of throughput ensures the solid matter being subjected to centrifugal force for about double the time and results in a greater quantity being extracted.

It is naturally more difficult to separate the minute particles of solid matter from viscous fuel than from less viscous fuel, and it may be that with fuels of less than, say, 1000 secs. such a reduced throughput is not really necessary. With the majority of fuels within this range no harm will be done by restricting the rate of throughput, but with some others it may happen that during the extended

time over which the fuel is subjected to centrifugal force other constituents of the fuel are extracted. When, therefore, comparatively light fuels are being purified and the centrifugal separator bowls require to be emptied more frequently than usual because of the extraction of a greasy substance, the question of increasing the throughput should be considered.

## PURIFYING TEMPERATURES FOR RELATIVELY LIGHT FUELS

From what has been noted regarding the relative weights of the liquid portion of the fuel and the solid matter in the form of insoluble ash, it will be appreciated that light fuels may not require to be heated to the same temperature as heavy fuels. In the case of some light fuels below 600 secs. viscosity, heating to 180 degrees F. will have no adverse effect apart from using more heating steam than is really necessary, but in the case of other fuels of similar viscosity but of different composition, temperatures in the region of 180 degrees F. may cause difficulties in the centrifugal separators owing to the waxy constituents being extracted with the ash and necessitating the bowls of these machines being emptied at very frequent intervals. When this occurs, the purifying temperature should be varied 10 degrees at a time until the wax-like substances pass through the machines with the purified fuel. In some cases it may be found that the fuel does not require to be pre-heated, the characteristics of the fuel being such that all insoluble ash can be extracted without such treatment.

## FUEL INJECTION TEMPERATURES

If boiler fuel has been properly purified, i.e., run through suitable centrifugal separators at the correct rate and at the right temperature, it will burn completely in the allotted time in most makes of marine Diesel engine provided that before it reaches the engine it is heated and its viscosity reduced to (1) ensure that it will flow freely to the H.P. fuel pumps, (2) avoid excessively high injection pressures, and (3) make it more easily atomizable.

In order to meet these conditions, the injection temperature requires to be between 160 degrees F. and 200 degrees F. When operating under normal full-load conditions, no difficulty is experienced in maintaining the correct temperature, but particular attention is required when starting an engine from cold or running at slow speeds for long periods in cold climates.

Before starting from cold, the fuel must be heated to the injection temperature and circulated for an hour or so to bring the pumps, pipes and all fittings in the system to approximately the normal working temperature. The circulating pump should be started before steam is applied to the heater. Only a little steam is required at first and then gradually increased during the first half hour, this to avoid local overheating of the fuel. The circulating hot fuel should extend as far as the fuel injection valves before returning to the inlet side of the heater. All pipes conveying hot fuel should be efficiently lagged with insulating material. Efficient lagging is particularly necessary when running at slow speeds for long periods and the rate of flow through the pipes is relatively slow, and when maneuvering in and out of port during cold weather.

## PRE-HEATING ENGINE CYLINDERS

It is always wise to pre-heat the cylinders of an engine before starting from cold in order to reduce expansion stresses as much as possible. In the case of a Diesel engine burning boiler fuel pre-heating is essential, since in addition to reducing expansion stresses in the castings the fuel injection valves require to be at a temperature that will not chill the fuel when the engine begins working. In most cases the fuel can be circulated prior to starting only up to the point when the fuel enters the fuel valve housing, so that the circulating water in the cylinder jackets is depended upon for heating the fuel valves and the fuel lying in them. The pre-heating of the fuel valves is of sufficient importance to justify the provision of a separate water-circulating system which can be heated to a temperature in the neighborhood of 140 degrees F.

In the 35 12,000-ton d.w. motor ships of the Anglo-Saxon tanker fleet now operating on high-viscosity fuels the wear rates of cylinder liners and piston rings are no greater than would have been expected had the engines been operated on Diesel fuel. To give the wear rate of each ship in detail would require more space than is available, and as the results are much the same in each case two ships have been selected as typical examples. The first is the Hawthorn-Werkspoor-engined *Auricula,* which was commissioned in August, 1946, and has operated ever since on boiler fuel, and the other is the Harland and Wolff-B. and W.-engined ship *Dromus,* built in 1938 and operated since November, 1948, on boiler fuel.

## PERFORMANCE OF THE ENGINE OF THE M.S. "AURICULA"

In December, 1950, this ship had operated at full power for 25,073 hours and the average wear rate of Nos. 1, 2, 3, 6, 7 and 8 cylinder liners at a point 4 ins. from the top of the piston stroke works out at 0.095 mm. per 1000 hours, which is slightly less than $\frac{1}{1000}$ in. per 1000 hours, the normal figure when operating on Diesel fuel.

In August, 1949, Nos. 4 and 5 cylinder liners in this ship were removed and replaced by two new liners in order solely to obtain information regarding the wear rates of an ordinary liner and a liner the bore of which had been chrome plated. The new ordinary liner was fitted in No. 4 and the chrome-plated liner in No. 5 cylinder.

Between August, 1949, and December, 1950, the engine operated for 6381 full-power hours and the average maximum wear for No. 4 liner worked out at 0.140 mm. per 1000 hours, and the chrome-plated liner 0.045 mm. for the same period. The wear rate of the new No. 4 liner is, it will be observed, greater than that of the six original liners. This is quite normal as the wear rate of liners is always greater during the first year's operation, and when No. 4 liner has been in service for 25,073 hours the wear rate will doubtless be the same as the six original liners within a small margin.

This ship will be five years old next August, when she will undergo her fourth periodical drydocking. During that time the 4000 i.h.p. engine has operated with entire satisfaction. No troubles of any kind have been experienced and not a single tide has been lost because the engine was not ready for sea. Actually, this ship has had more days at sea than similar ships which it has not been possible to equip for the burning of boiler fuels, because these ships drydock every nine months, whereas the *Auricula* in the normal way drydocks at 12-monthly intervals.

## CYLINDER-LINER WEAR OF THE M.S. "DROMUS"

This ship was 10 years old when equipped to burn boiler fuel in November, 1948, and the cylinder liners were nearing the end of their useful life. In order to determine the effect of burning boiler fuel in liners already badly worn it was decided to leave in place Nos. 1, 3 and 4 liners which had worn a maximum of approximately 5 mm. The remaining five liners were renewed.

After operating for 8395 full-power hours on fuels varying in viscosity from 1200 to 1500 secs., the old and new liners were gauged for wear that had taken place since November, 1948, and the maximum readings in mm. found to be as follow:

| | Fore and Aft | Athwartships | Mean |
|---|---|---|---|
| New Liners (5) | .. 0.124 | 0.149 | 0.136 |
| Old Liners (3) | .. 0.089 | 0.146 | 0.117 |

In respect of blow-past the piston rings there was no difference between the old and new liners, but the wear rate of the rings in the old liners was, as expected, greater, and two further old liners have since been replaced by new parts.

Apart from showing that if boiler fuel is properly treated before it is injected into the engine cylinders the wear rate of either new or old cylinder liners is no different from what could be expected when burning the much more costly Diesel fuel, the foregoing gauge readings are interesting inasmuch as they show how the wear rate varies during the useful life of cylinder liners. During the first year or so the wear rate is relatively high, and after the amount reaches what is usually considered the maximum permissible for liners of about 670 mm. diameter, namely, 5-6 mm., the wear rate again becomes relatively high, but not so high as during the period when a hard, wear-resisting skin is being formed.

# WELDING IN AMERICAN ENGINEERING EDUCATION

ACKNOWLEDGMENT

This article, published in the May, 1951, issue of "The Welding Journal," was written by J. HEUSCHKEL, of the Westinghouse Research Laboratories, East Pittsburgh, Pa. It discusses the results of a letter survey on the problems of teaching welding, welded design and welding engineering in colleges.

## I. INTRODUCTION

During the past thirty years, welding has become widely accepted as a means of fastening together the subparts of the many and often complex metallic assemblies that constitute the working mechanisms of a dynamic industrial and agricultural America. It is the function of the Educational Committee of the American Welding Society to continuously further a widespread understanding of the progressively expanding frontiers of knowledge which have been and are continuing to be achieved within the field of welded fabrication as the result of the combined efforts and experiences of research, development, application and educational personnel. As welding has become an increasingly important fabrication tool, it becomes more and more important that engineering students and their instructors recognize the fundamental importance of this method of fabrication, and also comprehend the technical problems which are peculiar to the usage of this method. It is therefore well that a legitimate professional contact be established and maintained between the Committee and the teaching staffs of the Engineering Colleges.

Heretofore, the Committee has been somewhat handicapped in knowing how to proceed with the treatment of possible problems in aiding the professorial staffs of the various accredited engineering colleges at the level indicated and as required or requested by those institutions. To alleviate this condition and to facilitate the future establishment of a high level of cooperation between industry and educators, a 1950 single letter survey was made of all the accredited American engineering colleges for the purpose of:

(*a*) acquainting them with the existence of the A.W.S. Educational Committee;

(*b*) pointing out that design for welding is one common meeting ground for most engineering students and it is also of funda-

mental importance from an industrial viewpoint;

(*c*) asking the views of the top level educators, meaning the Deans of Engineering and also the Heads of the Civil, Electrical and Mechanical Departments on the problems of teaching welding, welded design and welding engineering in the American colleges, and

(*d*) specifically asking the educators in which field of effort the Educational Committee could be of maximum assistance to the Engineering Colleges.

## II. SURVEY PROCEDURE

It was believed that such an evaluation of the efforts which the American Engineering Colleges are making to keep their students informed on the progress and problems of modern fabrication and joining methods could only be made after conducting an individualized survey. There are 137 accredited engineering colleges and universities in the United States.* To secure the desired information the letter of inquiry was addressed to the engineering dean or his equivalent, and to the heads of the mechanical, civil and electrical engineering departments of each of these institutions. This was done because it was thought to be impossible to classify colleges by any single type except by the branch of engineering in which degrees are conferred.

## III. REPLY RESPONSE

From the 137 institutions polled, a total of 205 individual faculty responses were received. At least one individual response was received from 84% of all the schools. Included were all of the large institutions. The detail reply distribution is significant:

| | | |
|---|---|---|
| Total schools polled | 137 | |
| Schools replying | 115 | (or 84% of total) |
| Replies from: | | |
| Electrical Engineers | 36 | (or 26% of total) |
| Deans | 42 | (or 31% of total) |
| Civil Engineers | 55 | (or 40% of total) |
| Mechanical Engineers | 72 | (or 52% of total) |
| Individuals | 205 | (or 38% of total) |

A general widespread interest therefore exists in this subject with maximum interest among the mechanical engineers and a minimum among the electrical engineers.

## IV. FUNDAMENTALS IN ENGINEERING EDUCATION

The responses repeatedly chronicle the problem of specialties education as being essentially that of allotting the proper proportion of the total available time to furtherance of knowledge within the scope of the activity in question. The basic concept of modern education involves training in fundamentals; in promoting the ability to think through a new problem; in recognition of the fact that the individual engineer is a member of a social unit and that his pro-

* Brumbaugh, A. J., "American Colleges and Universities," 5th ed. (1948).

fessional work both influences and is influenced by society; and that the engineer is an intelligent citizen first and professional man second. All this the undergraduate student is to absorb, usually within a four-year program!

The colleges recognize their responsibility in providing a sound grounding in fundamentals including mathematics and mathematical analysis, physics, chemistry, etc. It is the foundation of their basic policy. It also is essentially the same as, and in the future may become even more nearly identical with, the European University practice of teaching engineering as a broad functional field of activity, not ignoring the fact that engineering also extends into the domain of management. It must be recognized therefore that the teaching of a specialty often comes into time limitation conflicts within a four-year curriculum.

The educational problem is thus compounded by the complexities of modern science; the trend toward functionalization; the tendency toward leaving details up to industry and the repeated impact of economic and military upheavals.

Progressive industry expects the educational units to stress fundamentals and later expects to train the individuals in the necessary specialties. The welding industry then is particularly interested in knowing whether the colleges recognize that welding is fundamental to modern fabrication techniques, if enough of industrial management is aware of the need for graduate education within this field, or whether each is expecting the other to cope with the problem.

Differences of opinion were received on this:

(*a*) "Our time to make improvements is limited and we give priority to the more important things, which in my mind are the fundamentals."

(*b*) "Can we not assume at this time that welding and welding design is as basic as riveting and riveted design?" and, again,

(*c*) "I am in sympathy with the present scholastic trend toward emphasis on fundamentals but I do not believe that increased instruction in welded design is necessarily in conflict with that trend. Regardless of generalization, we will undoubtedly continue to teach liberal amounts of elementary design and it is my opinion that the design courses must be revised to provide for instruction in welding in proportion to its increasing importance, relative to other fabrication processes."

The Committee may do well to clarify the possible ways and means for furthering the inclusion of welding principles as a part of training in modern engineering, since fabrication of metals is fundamental to the construction of all metallic products and welding is involved in so many instances. The important point is to provide enlightenment in limiting principles, not in training students to be welders. The student should be given "an appreciation of the possibilities, potentialities and limitations of welding and made aware of the current status of welding in the engineering profession." The trade schools should be encouraged to train both operators and technicians in the field of applied welding, which is not an engineering college function. One may close this phase of the problem with the comment of a prominent engineering college professor:

"The scholastic trend in engineering education in the last decade has been toward accenting pure science and the humanities, rather than shop and vocational courses. While we in the Metal Processing Division feel that this trend is on the whole a proper one, we do believe that improper emphasis has been placed on certain aspects of it. The science student is often—the engineering student rarely—interested in fundamentals for their own sake. Unless the

latter is given an engineering focus for his fundamentals, he rarely remembers them beyond the term examination. Thus, the emphasis should be, not on science courses, but on engineering courses taught by men who are more conscious of the fundamentals and of their applications to engineering."

## V. HUMANITIES IN ENGINEERING EDUCATION

Huxley, many years ago, defined a liberal education as "a training of the mind and the will to do the things you ought to do at the time they ought to be done, whether you like to do them or not." The present trend toward more training in the liberal arts and humanities and the resultant problems was pointed up by the comments:

(*a*) "You are perhaps aware of the difficulty that we have had in trying to increase the nontechnical course work offered to engineering students. Some of our friends in the art schools have blamed almost all of the world's ills on the fact that we get so little work in the nontechnical field that we are almost a menace to humanity. Even so I think I could prove to them that most engineering curricula are designed with far more nontechnical content than the equivalent curricula in the art school. I think if you check up on the curricula offered to doctors, lawyers, English majors, and others you will find that the engineer has more nontechnical work outside his own field than any of these."

(*b*) "At present due to the clamor for more liberalized engineers we are eliminating basic technical courses for work in American Democracy and Western Civilization. In spite of this we are constantly criticized for giving our students twenty credit hours per semester compared to fifteen hours in liberal arts colleges. A good part of this work is laboratory too."

(*c*) "The result is that we must teach the fundamentals in the sciences and in engineering with only a few courses available for teaching the art of engineering."

(*d*) "With the introduction of considerable work in the humanities and with a reduction in the number of credits required for graduation, there has been a reduction of one-third in the amount of drawing in the freshman and sophomore years. Thus the students no longer receive training in welding symbols."

These factors of educational policy are a prelude to the problems of the Committee. They point up the need for an acceptable answer to the observation that, "it is very easy to add new courses, presuming time is available for such addition, but it is extremely difficult to decide which courses may best be removed in order to make way for something new."

## VI. TIME—THE ESSENCE OF THE PROBLEM

Time is the essence of the educational problem, and more responses mentioned this than any other one factor. Heretofore, the practice has been to maintain a four-year undergraduate program. There is a trend to change this to five years. There are also both policy and economic objections to this change. Would such a change further restrict opportunities for the able but less fortunate individual? There is a problem in increased efficiency in engineering education, as there is in engineering application, including production. The Committee could well give thought to this problem by studying the best ways for the incorporation of welding problems into existing courses. Time may be recognized as being the essence of the problem without its shortness being accepted as an unsurmountable obstacle, even in the four-year course.

## VII. THE CASE FOR WELDING

Welding is no longer a luxury specialty. It is now a basic tool of modern industry and is being used to a lesser degree in structures. A more widespread understanding of its usage is fundamental to modern production. Notwithstanding that objections toward including technical aspects of welding in the engineering curricula include the desire to emphasize fundamentals and humanities, which leaves little or no time within a four- or even five-year course for specialties, and that there are many specialties in the present era, there were strong opinions in favor of such inclusions from many sources:

(*a*) "Your letter regarding the offerings of the colleges in the field of welding and welding design, and requesting suggestions to improve the offerings opens an entire field of discussion and argument."

(*b*) "It is my firm belief and has been for some time that welding should and must be incorporated in the education of the engineering student. We older men who went through college when welding was in its infancy and riveting still the accepted practice are aware—perhaps more than the younger men—of the tremendous change in design practice that has been brought about by welding techniques. Textbooks rarely bring this out and the only way the student will become aware of this is by supplementary instruction given by the instructor."

(*c*) "The emphasis which a department of engineering in an American College gives any one group of courses in its curriculum depends, I think, on the demonstrated need for that emphasis. I have no doubt that a much better foundation could be given in welding here, but only by sacrificing the foundations of some other branch of engineering."

(*d*) "My staff feels that it would be definitely advantageous for all engineers and designers in product design and manufacture to have a fundamental background in welding and welding processes."

(*e*) "This is a subject about which I am very much concerned and I feel that as engineering instructors we are not doing what we should in this field. We spend some time on this subject in our Strength of Materials course and I devote a reasonable amount of time to it in my Machine Design class."

(*f*) "Students are graduating today with very little knowledge of the practical use of materials. Most of them simply cannot 'use their hands' even in the simplest of operations using *wood*. Our present emphasis on theory and fundamentals has eliminated shop courses. We have no shop work.

"I, frankly, do not know the answer. We are definitely *not* training mechanics but the graduate who goes into Design has a long road ahead of him before he can do a job. Industry is very largely responsible for this situation as the insistance has been for fundamentals in college with practice in employment."

(*g*) "I believe that a welding course should demonstrate to the prospective engineer the various types of welding processes used in industry today, rather than delve in the fundamentals of arc welding and gas welding mild steel. In addition to the various welding processes being used in industry, the student should know something about welding design, cost of welding, testing of welds, etc."

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There are also objectors to any inclusion of the subject in any form.

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## VIII. WELDING METALLURGY

Ways of introducing the fundamental welding concepts into the undergraduate curricula are pointed out by the various procedures already in use. Among these are the 13% of the total replies who now report that basic factors of metallurgy are being given, or offered, to civil, electrical and mechanical engineering students. Metallurgy is an important subpart of the welding problem. Approaches for consideration include:

(*a*) "It would be desirable if such a course could have as a prerequisite a general course in Physical Metallurgy."

(*b*) "The actual analysis of welds is covered in the course in Physical Metallurgy, which is taken by all engineering students except those in electrical engineering, and they are anxious to have it in their curriculum."

(*c*) "Our mechanical, marine, aeronautical, business and metallurgical engineering undergraduates all receive at least one course in metallurgy which includes the fundamentals of welding."

(*d*) "Our students of Civil Engineering who elect the structural or the transportation option take a course titled 'Metallurgy and Welding' in the first term of the Junior year."

(*e*) "Mechanical engineering students are required to take a course in the fundamentals of ferrous metallurgy. This course is now taught in the School of Chemical Engineering. Later, they take a course in heat treating, consisting of two hours lecture and three laboratory hours per week, for one quarter. A considerable portion of the laboratory time is devoted to microscopic examination of heat-treated steels."

(*f*) "We teach, of course, a course in metallurgy which will be in our fifth year, that is after the student has had a year of shop training. This ties in very well and it is more or less beneficial to have the metallurgy course follow the regular shop courses."

In so far as they have adopted this approach, the schools have done well.

## IX. WELDING DESIGN

### *1. General*

There are certain design factors unique to welded fabrication. Design for use of the specific welding process to be used is one. Consider the metal welded and the service requirements. Avoid overwelding; it is costly and in some instances may be harmful to the integrity of the final product. Designing is the function of the designer; yet how can the design be proper for welded fabrication if the designer is unversed in the usage and requirements of the welding processes? How is the designer to become aware of these usages and requirements? By trial and error? And if this be the method is it not cheaper to pre-educate than to bear the cost of the resultant inevitable errors?

The inquiry letter stressed design as one area of mutual interest common to all branches of engineering. Perhaps for this reason 55% of the replies comment specifically on this subject. But it was found that, while the welded design problem is a phase common to all branches of engineering, the emphasis varies considerably between different departments.

### *2. Civil Engineers*

The civil engineers are faced with the fact that only about one-third of static structures involve the usage of welded fabrication at this time; not long ago it was used in less than 10% of such structures. It is almost universally used on piping and storage tank projects. Thus they report for example:

(*a*) "You are seeking information on a timely and touchy subject in the field

of structural design. As you mentioned in your letter, the trend toward welded design is growing by leaps and bounds, and it is rather unfortunate that colleges in general have not been able to give more emphasis to the subject. But are we to more or less completely eliminate an old and well-established method, for the new, at this particular time? It would mean rather drastic changes in the subject matter of our curriculum if we were to give welding the emphasis it deserves; for although welding brings up many new and unusual problems, riveted construction is the more difficult to grasp in the long run, and I think you will agree that the majority of structures are still being riveted even today." (I did in preceding paragraph.)

(*b*) "We stress the fact that any structure to be welded must be designed for welding in order to take full advantage of welding. The various disadvantages of welding are also considered. Our men have had previous instruction in principal stresses so they are able to appreciate the problems and approximations involved with respect to internal stress conditions."

(*c*) "Perhaps the most valid reason for our lack of emphasis on welding is that structural welding has not come into common use in this section of the country. No welding whatsoever, to our knowledge, has been used in railroad and highway bridges in this part of the country (the Pacific Northwest), although very recently highway specifications have begun to include some welding codes. Likewise, there has been very little welding in building construction. Fifteen years ago I was firmly convinced that welding in building work was rapidly coming to the fore. At that time I was teaching structural design and included a problem in welding in my regular class work. However, this anticipated development simply has not come about in this part of the country. I am not sure of the reason, but I do know that some fifteen years ago we were having some considerable difficulty with the welded structures which were going up at that time. This difficulty may have had some bearing on the reluctance to use welding in this area."

One may ask if the difficulty 15 years ago was in the process or in the lack of knowledge.

(*d*) "It is my impression that the colleges of the country are becoming more aware of the importance of welding in structural design and if the trend here is any indication they are devoting more attention to it. However, there is little chance that any four-year curriculum will have a separate course in welding for the undergraduate students. It is now handled within the regular structures courses and considered merely as one of several means of making connections between members of a structure."

Civil engineering reports that the material now being given is usually included within the framework of one or more other courses as:

Sophomores—Shop
Juniors—Mechanics of materials
Stress analysis
Elementary structural design
Seniors—Structural design
Structural steel
Construction planning and management

Presented material includes:

(*a*) Short shop course in weld manipulation and technique.
(*b*) Types of welds and their applications.
(*c*) Use of standard welding symbols.
(*d*) Brief discussion of advantages and disadvantages of welded construction compared with other methods of fabrication.
(*e*) Discussion of fatigue characteristics of welded joints.
(*f*) Discussion of properties of welded material.
(*g*) Design of welded tension joints.
(*h*) Design of welded compression joints.

(*i*) Design of welded splices and connections.
(*j*) Design of welded plate girders.
(*k*) Design of welded trusses.
(*l*) Design of welded built-up beams using the A.I.S.C. specifications.
(*m*) Design of welded connections for small truss members that are unsymmetrical.
(*n*) Considerations of light metals, as aluminum alloys.
(*o*) Making of load-slip determinations, riveted and welded.
(*p*) Continuity in frameworks.
(*q*) Practical features.
(*r*) Theory and practice, including residual stresses; distortion; stress concentration and fatigue; technique of welding, including laboratory demonstration and practice welding; current design specifications; examples of recent designs of bridges and buildings; relative economy studies—riveted vs. welded construction.

*3. Electrical Engineers*

Electrical engineers are primarily concerned in teaching theory of electrical phenomena and systems and place little importance to the mechanical design of such items as electric motors, for example. They generally ignore the problems of design for welding. This, to the author of this report, was one of the most interesting disclosures of the survey, considering the known daily welding design problems encountered by a large electrical manufacturing company. Their treatment of the subject is highlighted by one comment:

"Are you aware of the fact that at least in electrical engineering most colleges teach no design whatever? We teach general theory, and physical concept with practically no design of any kind. Some time ago I became disturbed over the fact that in electrical engineering unlike practically all other engineering courses, we had practically no design work whatever in our University. We therefore installed three new courses (actually courses which had been dropped out years before) in the electrical engineering design of machines. I am quite aware that our methods of design will probably be different from those used in industry and that any of our students who get into design work of machinery will have to relearn all of the design principles. On the other hand it seems to me that the end product of all engineering is the design of *something*. In all other engineering courses the students spend hour after hour in designing mechanical, civil or chemical engineering mechanisms or structures. In electrical engineering on the other hand we have got so far away from the idea of designing something that it has seemed unsound to me."

*4. Mechanical Engineering*

The mechanical engineers, in nearly all cases reporting, include welding as some part of their design courses, in addition to considerations in metallurgy and mechanics of materials. They put most emphasis upon the subject within the area of machine design, which can and probably does include electrical machines, but the subject is also treated in other courses, as:

(*a*) Machine design.
(*b*) Machine analysis.
(*c*) Tool design.
(*d*) Tool and die design.
(*e*) Machine tool operations.
(*f*) Metal processing.
(*g*) Engineering drawing.
(*h*) Shop practices.
(*i*) Production methods.

For example, one instructor reports that, "In Principles of Machine Design, given the first term of the senior year, the elementary stress analysis of welded joints is considered along with analysis of other fasteners. Problem work is given on stress analysis of simple joints in tension, tension and shear, and in shear. Structural joints in primary and

secondary shear are designed both for riveted and welded construction. Some work on pressure vessel joints for welded and riveted construction completes the coverage save for lecture work on various welding processes and applications. In the second design course, Mechanical Design, complete design projects are carried out. The student is free to choose and apply welding to all the parts where welding and brazing might be used to advantage."

Other items covered include:

- Welding practices and techniques.
- Basic principles of welded design.
- Production methods, including welding.
- Welding symbols.
- Design calculations.
- Stress analysis.
- Strengths of welds and welded joints.
- Design of welded pressure vessel.
- Considerations of welding, riveting, forging and casting.
- Distortion from welding.
- Accessibility.
- Selection of materials.
- Welded tool design.
- Welded joints in tension and torsion.
- Thermal stress determinations in bimetallic members.
- Biaxial and triaxial stress conditions.
- Methods of assembly and jigging.

One schools offers "an elective course to seniors titled, 'Welding in Design,' which picks up the problem from the standpoint of the metallurgy of the welds and its effect on the materials being joined and carries through to actual design problems in which welding is a means of fastening."

Another reports that "One thing that we do stress is that welded design is a subject by itself. In machine design, for example, the designer should not imitate the structural steel designer and neither should he necessarily make the parts look like castings. I feel that with a reasonable amount of time and study devoted to this subject, we can improve, to a large extent, our method of instruction in this field."

The supporting arguments for the procedure of teaching welded design as a separate course are furnished by yet another commentator:

"There are too many other topics which must be covered for an individual instructor to do the work necessary to make much improvement in the presentation of the design of welded joints during the time devoted to the average machine design course. This work should be done by those with much experience in the field of welded design and the methods should be fundamentally sound and backed up by the necessary data to convince the student that the presentation is logical and that the methods are to be depended upon."

Only a few departments reported a complete absence of interest in welded design. The general soundness of the mechanical engineering instructors may be summarized with the one observation:

"I feel personally that more attention should be paid to designing for welding. I also feel that attention should be given to the use of welding as against castings. I also feel that such instruction should be honest and unbiased; and where a good steel casting would be superior to a weldment, the instruction should be such as to permit honest discrimination. This statement goes for the tendency to substitute steel castings for a part that could be more satisfactorily welded. The basis for instruction, welded or cast, should be in the design course. Thus the engineer remains the engineer and does not become the welder first."

## X. WELDING PROCESSES AND TECHNIQUES

From the ancient Greeks comes the expression, "We learn by doing." While it can readily be agreed that the engineering college student is not a candidate for a job as a welder, welder foreman or supervisor, "he should have some knowledge of welding methods and procedure. With this background to build on, he should be able to handle the engineering aspects of the modern trend toward welded fabrication."

For example, one school gives 30 clock hours instruction of shop training in arc, gas and spot welding. Others commonly give a one-credit laboratory course, often in the freshman year, but sometimes in the senior year. Such courses are "primarily intended to demonstrate methods, equipment, precautions and control in welding." These laboratory courses are often required and embrace one or more branches of engineering. Depending upon the individual school, the work is included under one of the headings: Manufacturing Processes; Welding, Heat Treating and Casting Laboratory; Materials and Processes; Advanced Welding Practice; Practices of Welding; Mechanical Processes; Welding Shop; Welding Laboratory; Welding and Pipe Shop Work; Welding Techniques; Structural Welding; Materials of Machines; Metal Processing; Materials Testing Laboratory (Demonstration); Industrial Electronics (E.E.); Metal Fabrication; Electrical Engineering Laboratory( incidental to operation of electronic controlled welders); Machine Shop; and Farm Mechanics.

This work is often supplemented with usage of motion pictures showing welding and welded applications.

Shop work requires equipment. This is a major deterrent in some instances, particularly within the field of resistance welding, a matter which may be reflected into the future detriment of that phase of the industry.

At one school "Civil and Mechanical Engineering" students in their senior year may elect a one-credit hour course in Structural Welding. This is a very practical course and includes:

"(*a*) Three lessons devoted to practice arc welding, culminating in each student making a standard fillet-welded tension specimen, which is inspected, judged and then tested.

"(*b*) The theory and design procedures for beam-column connections of the simple, fully fixed and semirigid types.

"(*c*) Arc-welding speeds, costs, inspection.

"(*d*) Theory and design procedures for various joints involving butt, fillet welds and slot welds.

"(e) A lecture on rigid frame analysis, and design for welding."

This later arrangement is also offered by others who report that: "At present we are offering courses in welding, machine shop and foundry work to fourth-year mechanical and electrical engineers—that is under our five-year program for a bachelor's degree in one of the engineering fields. Our reason for placing these courses at so late a time is because we feel a student will obtain a great deal more out of them than he would if he were in the freshman year like the majority of other universities. In fact, we feel that since students are more mature we can give them a great deal more in the allotted time and also that when they are finished with these courses they immediately go into other machine design courses."

Early or late, the practice of giving welding instruction is growing:

(*a*) "This semester we are teaching a new course known as Applied Welding Technology for Engineers. This is an elective course and quite a few of the

Civil Engineering and Architectural students are evidencing considerable interest in it. We are confident that the interest in this course will continue to grow when it becomes better known."

(*b*) "We would like to briefly describe a new program to become effective this fall."

"During the sophomore and the first half of the junior year we will teach a series of coordinated courses under the general heading of 'Engineering Materials and Manufacturing.' One phase of the work will deal with the welding of metals and will include pictures and welding demonstrations. We will teach the fundamentals of welding, but will not attempt to teach the students how to weld. We constantly try to maintain our objective of developing future engineers and not journeymen."

Fortunate indeed is the school able to report that:

"We offer both theory and laboratory welding classes in the engineering curriculum. The welding laboratory is now adequately equipped with electric arc and oxyacetylene welding equipment, and we hope to have other modern equipment, such as inert-arc welding, soon for student use. We are giving the engineering students more theory now than we have in the past. Some of the information included is as follows: welding fabrication, economy, design, weldability of metals, pretreatment and aftertreatment, jigs and fixtures, inspection and testing, and the welding processes. Numerous up-to-date pamphlets and books on these subjects are made available for student use.

"Previously we were handicapped by inadequate facilities, but during the past year some of these have been corrected. It is our desire to continue to improve the facilities so that engineering students can have more instruction on the problems created by the trend toward welding fabrication."

or again that:

"We cover such topics as oxyacetylene welding and cutting equipment, electric arc welding, manual and automatic applications, including submerged arc, gas-shielded arc; and other welding processes, such as atomic hydrogen, pressure and resistance welding, testing of welds, control of distortion, basic metallurgy of welding, welding electrodes and their classifications, preparations of joints, including their symbols, and factors involved in estimating costs of welding are discussed.

"The fundamentals of design for arc welding are covered by lecture and also by the actual construction with jigs and fixtures of simple structural parts, such as levers, link and clevises, wheels, gears, etc. Use is made of automatic welding heads, welding positioners and other fixturing devices to show how these parts can be set up on mass production basis.

"We have a well-equipped welding laboratory with all equipment mentioned above, not only for lecture demonstration, but also for the students to actually use in the various types of welding."

Another school reports that:

"In industrial radiology of course sample welds are used in both X-ray and gamma-ray exposures and the common types of defects are pointed out. We also give some attention to welded items in magnaflux and zyglo inspection which may be included in any one or more of the courses enumerated. We have very good equipment for all of this work and I am sure you appreciate not only the application advantages of welding but also the problems of a research nature that still exist."

Under ideal conditions,

"Both pressure and non-pressure welding and allied processes, such as brazing and soft soldering, are covered by means of lectures, demonstrations, films and laboratory work. Forge welding, electrical resistance welding, thermit welding, carbon and inert arc welding are

covered by lectures and films only; oxy-acetylene welding is covered by demonstrations and films; electric arc welding is covered by lectures, films, and actual laboratory practice. The welding of low carbon steel, of course, is given the main consideration, although the welding and brazing of cast iron, aluminum, and stainless steel are also discussed and covered by use of films. A limited amount of laboratory work is devoted to the arc welding of cast iron."

However, for any one school, time is yet an essential factor and again we are reminded that "If there is any way of covering the subject of welding in a thorough manner, using only 12 to 18 hours of the student's time in Machine Design and approximately the same amount in shop practice, I would be very happy to find it."

Here is a challenge to the Committee!

## XI. GRADUATE INTEREST

Having acquired a B.S. or B.A. degree, the young engineer is often encouraged to proceed with specialization and at this time there is an opportunity for more widespread choice for fields of activity. About 10% of the replies indicate that the schools now offer, or hope to include, welding (design or metallurgy) in their graduate programs, for civil, electrical and mechanical engineering students. Again, too, there are objectors! Constructive observations include:

(*a*) "Graduate students in Civil Engineering may elect a three-credit hour course in Structural Welding."

(*b*) "It is my personal opinion that if a student wished to pursue graduate work in welding from an electrical engineering standpoint, he would be much better off to gain some practical experience in the work before proceeding with his graduate studies."

(*c*) "Next fall I shall give a course in the utilization of electrical energy in which among other things I expect to cover briefly the electrical principles of the various types of welding, welders and controls. This course will probably attract graduate students in mechanical engineering and possibly some graduate students in electrical engineering.

"As we work into the field of electric welding and welding machinery, I expect to include a discussion and experiment on it in the undergraduate final machinery course, probably for the first time in the spring of 1951."

(*d*) "Many of our graduate students take our two-term course in metallography followed by a one-term course on industrial radiology. In the first term metallography course there is some attention to microstructure of typical electric and gas welds and in the second term, which is taught by the project method, we not infrequently have students take some phase of welding as the subject of their study. In this course two students work together on either an assigned project or one of their own choosing."

## XII. TRADE SCHOOL & TECHNICIAN TRAINING

The survey being reported was deliberately confined to the accredited engineering colleges. It is recognized that there are other institutions that do an excellent job at training men in a needed but somewhat different category. However, if all welding design and engineering were to be confined to those schools alone the young engineer would find himself with a viewpoint on construction and fabrication that is already obsolete—a somewhat frustrating experience. There is, however, an excellent opportunity for the intermediate colleges to fill a badly needed gap by the adequate training of technicians in the welding field.

## XIII. WELDING ENGINEERING

Only one university in America treats welding engineering as a unique undergraduate subject, although others give options in this general field. The engineer who devotes his professional lifetime to this specialty is yet within a classification meaning all things to all people. Nevertheless more and more, industry finds need for the highest form of intelligence, with engineering training, to handle this portion of activity.

## XIV. INDUSTRIAL TRAINING

The "easy out" is cited by many; let industry do the necessary training. "We think that they can learn the more difficult problems in practice." One may add, this is effective only if industry provides the necessary preliminary training so that it doesn't cost too many failures before the young engineers learn how to do their job properly!

Actually, progressive industry accepts the concept that the graduate engineer is not ready to do a job, that he needs special training first. The better arrangements involve extensive expenditures in money and effort. But does and must all industry train men in all things? It is stated† that "the advanced courses taught by industry fifty years ago are part of the undergraduate curriculum of today's schools. Now, advanced courses have soared into fields and sciences that in some cases were unknown a half century ago." The point is, welding is now and has been for some time an important fabrication tool. The general concepts should be and are gradually being shifted into the undergraduate curriculum, now. Acquaintance with year-to-year advances do belong within the scope of industrial training.

The pros and cons of this controversial subject are put forth by two correspondents:

(*a*) "The smattering of knowledge that one gains in college about a specialty can never be completely adequate and will never be completely representative of the many variations of the techniques of that specialty employed by different companies. Over-all economy dictates that the employer of a college graduate should teach that employee the special techniques so that he won't have to unlearn some things he was taught in college."

(*b*) "I do not completely subscribe to the principle that the detailed and specialized training may well be left to the industrial organization that employs the young graduate. I feel that the Civil Engineering graduate, in particular, should be able to take his place in the practice of his profession with a minimum of subsequent training and instruction provided by the employers. To this end we try to keep our own program as flexible as possible and to give at least basic instruction in the possibilities and practice of welding."

† "Westinghouse Engineer," Nov. 1950, "Education in Industry."

## XV. INDIVIDUAL STUDY

Whether or not formal industrial training is offered, these growing fields of engineering require a continuous application through individual study. The students will find that all branches of science and engineering contribute to the make-up of the solutions of the welding problems.

Most present-day welding engineers followed this route. Perhaps the writer

may be forgiven for inserting a pertinent quotation from The Analects of Confucius, "When I attained the age of 15 I became bent upon study. At 30 I was a confirmed student. At 40 nought could move me from my course. At 50 I comprehended the will and decrees of Heaven. At 60 my ears were attuned to them. At 70 I could follow my heart's desires without overstepping the bounds of rectitude."

The successful engineer is the continuing student. Who else can survive in this area of rapid and radical progress?

## XVI. POSSIBLE AREAS OF MUTUAL ASSISTANCE

The Committee was interested in learning of the various existing needs as interpreted by the teaching staffs. Specific descriptions of those areas of invited assistance were freely given.

### *1. Instructors*

Only three replies pointed to a desire for new men in this field, one of them stating that "I have been looking for the past two years for a man to teach machine design who will have some background experience in welded design as well as some analytical work in his own field but I find that such a person is just not to be had."

Others elaborated upon this theme:

(*a*) One found that it was necessary to offer an evening (M.E.) course "so that we may secure the services of an experienced man from industry as instructor. This course has been quite popular, as many of the better students sense the desirability of a practical course of this type."

(*b*) Another commented that "the average teacher tends to offer and emphasize those portions of the subject or field with which he is most familiar, or in which he is most interested." Therefore it appears natural for another correspondent to suggest that

(*c*) "One of the biggest aids that industry could give to the schools would be for such organizations to set up six weeks scholarships in the summers with all expenses paid to encourage college teachers to learn at first hand the most recent development in field practices in welding."

(*d*) Another similar comment was that "the problem in teaching many engineering subjects is to keep the instructor aware of the frontiers of knowledge in the fields and keeping him informed of trends and directions of development. True, if one had the time, he could read all the papers published in a particular field, but it is necessary for one to work actively in a field to timely appraise the value of the published material."

The Committee may well study the best ways for establishing a system which will:

1. Encourage competent designers and engineers to enter the field of technical instruction,
2. Encourage the various instructors to spend summer and sabbatical leave periods studying the conditions, needs and methods of industry,
3. Encourage industrial management to provide a means for established instructors and professors to learn first hand the problems and techniques of industry, and
4. Develop a system for transmittal of the best of new information within the welding field, probably upon an annual basis, to all interested teaching personnel.

### *2. Course Organization, Outlines and Methods*

One out of each four replies requested information on organization, methods and minimum requirements for teaching the subject matter involved. Specific requests include:

(*a*) Provision of minimum welding essentials and specification of the ingredients of a best foundation in the principles of welded design.

(*b*) Provide results of survey on education so that a comparison with other schools' methods can be made.

Publication of this report fulfills this request.

(*c*) Provide the recommendation of the Committee on the matter of teaching welding and welded design.

(*d*) Provide any material, suggestions or outlines which the Committee feels will be helpful.

(*e*) Provide an outline of the material essential in the training of an engineer who will deal with welding in some form in his professional work after graduation.

(*f*) Provide ideas: textbooks, source material, practical applications, methods used in other colleges.

(*g*) Provide material on practical problems in welding design suitable for laboratory fabrication and testing.

(*h*) Establish a system of frequent contact with the interested instructors.

The Committee is assured of the sincerity of these requests and is repeatedly challenged to provide solutions by such frank comments as: "This question of teaching welding design has always been a problem for me. If you develop any method of teaching welding design in the time allowed in our crowded undergraduate curriculum, I would certainly appreciate learning of it."

## XVII. ADEQUACY OF AVAILABLE MATERIAL

The quality, quantity and adequacy of available reference material is also a matter of controversy. More than 10% of the replies indicated dissatisfaction with existing information. The needs were well summarized by eight different commentators, which blend into one unrehearsed chorus:

(*a*) "There is a lot of material in print on welded design, but most of it deals with specific examples or is of a promotional nature, and at times it is hard to distinguish the grain from the chaff, so to speak. The material on welded design in college textbooks should, therefore, meet the following requirements:

"1. It should be unbiased, not just a sales talk on welding, but an attempt to represent welding in its proper perspective in relation to casting, forging and other methods of fabrication.

"2. It should emphasize fundamentals and basic principles in welded design, such as calculation of stresses involved, in the effect of stress risers, location of welds, cost, types of construction that can be used such as, for example, the box-beam type, how to cope with distortion, how to eliminate weight, how to improve the appearance of welded products, how to design jigs and fixtures for welding, etc.

"3. It should attempt to teach the student to use a new approach in designing for welding, not just merely thinking in terms of old methods of fabrication such as riveting, for example."

(*b*) ". . . the most up-to-date material on advancements in welding and welded design is certainly desirable. The best job of presenting good foundation material to the most students of design will come when writers of textbooks are themselves properly informed and can include such material in a clear and permanent form. Efforts of individual instructors to keep informed by their own

research in order to pass it on to students, are of course probably helpful to their own students; but such efforts result in much variation in selection of material, quality of material, and (since it involves another demand on instructor's time) quantity of material.

"It would seem to me that the easiest method of getting to the writers would be by cooperation with the publishers who usually know of textbook work in progress.

"Textbooks which are presently used discuss different welding methods, weldability of materials by some of these methods, and analysis of stresses in simple welded joints."

(*c*) "The fundamentals of welded design are treated in a very elementary manner in most texts on machine design. The average student loses interest almost immediately upon reading some of the general statements and finding only the simplest principles of stress analysis applied to welded joints. Machine design texts are undergoing a change toward more emphasis on fundamental principles rather than presenting the force analysis of stereotyped assemblies. The student has been trained beyond the empirical methods used in the presentation of welded joints in the average text; it is a distinct letdown and a disappointment to him."

(*d*) "If the welding industry prepared a first class textbook, the problems and solutions of which are worked up by an experienced teacher of engineering students, under guidance of an expert welding designer, then the experience of practical designers could be combined with the experience of presentation. Experienced engineers know their work but frequently fail to grasp student psychology. Our teachers do not know modern welding design. *Let us get together.*"

(*e*) "It has been my hope that in the future the Welding Society would come out with a good book bringing out first, the metallurgical considerations; secondly, an exhaustive section on properties not only of the metals welded but of their geometry after welding, and also such considerations as notch effects, fatigue, dynamic loading, triaxiality, etc. Finally, design practices could be brought out.

"Perhaps this is a large order, but I believe that a book of this sort would do much toward the ends of instruction in a technical school."

(*f*) "If a good handbook were made available for distribution to students in the design course there is no doubt that we would at least add to our present coverage."

(*g*) "As far as teaching welded design in engineering colleges in the future is concerned, unbiased material on welded design will have to be incorporated in the textbooks themselves all of the way along the line from the shop courses, through mechanics and mechanics of materials to machine and structural design. Many present-day textbook writers are themselves not acquainted very thoroughly with welded design. So, I also heartily recommend that sections or chapters on welding be written by welding engineers. Books on machine design are getting to be too much for one man to write anyway—they should be cooperatively written by several men."

(*h*) "We have found it rather difficult to abstract material from the publications of the American Welding Society and other interested organizations for presentation to undergraduate students. The problem is further complicated by the lack of time or thorough grounding in the more fundamental aspects of welded design."

## XVIII. REFERENCES BEING USED

In the absence of more nearly ideal material, as described by the foregoing, the following were reported as being used:

*Books:*

*Welding Fundamentals*—Rigsby
*Weld Design*—Churchill & Austin
*Welding & Its Applications*—Rossi
*Structural Design in Metals*—Williams & Harris
*Design of Machine Members*—Vallance & Doughtie
*Design of Machine Elements*—Faires (Chapt. 19)
*Design of Modern Steel Structures*—Grinter (Chapt. 3)
*Manufacturing Processes*—Begeman (Chapt. 8)
*Tool Design*—Donaldson & LeCain (Chapt. 7)
*Metals & Plastics*—Thomas P. Hughes

*Technical Society Literature:*

*Standard Welding Symbols*—American Welding Society
*Std. Specifications, Welded Highway & Railway Bridges*—A.W.S.
*Welding Handbook*—A.W.S.
Welding Journal—A.W.S.
A.I.S.C. Specifications

*Industrial Publications:*

*Arc Welded Steel Structures—Design Manual*—Air Reduction Sales Co.
*Practical Arc Welding*—Hobart Bros.
*FLEXARC Data Book*—Westinghouse Electric Corp.
*Lessons in Arc Welding*—Lincoln Electric Co.
*Procedure Handbook of Arc Welding*—Lincoln Electric Co.
*Design for Welding*—Lincoln Arc Welding Foundation

## XIX. MATERIAL REQUESTED

(*a*) "It would be helpful if we could have more information on various types of welding, various applications, with specimens of typical welded joints. More information on advantages and disadvantages would be helpful."

(*b*) "We would appreciate receiving any material which would help give our engineers a good background of welding information."

(*c*) "Any charts or supplementary material such as A.W.S. rod specifications, welding symbols, tests for qualifying welding operators, that you send us will be deeply appreciated."

(*d*) "We would appreciate receiving literature which you may have available which would assist us in bringing to the attention of our students the latest information on welded fabrication of industrial equipment and structures."

(*e*) "We would also like more information on the limitations and costs of welding as compared with other types of joints."

(*f*) "I believe it would be advantageous to have material covering applications of welded construction in all phases of civil engineering."

(*g*) "Are copies of the *Welding Handbook* available for purchase at student rates—or are excerpts from the *Handbook* available for distribution to students?" (The answer is that the A.W.S. *Handbook* can be secured at student rates, a 33⅓% discount, but still $8.00.)

(*h*) "We should be pleased to receive information on the following:

"1. Characteristics of a good spot weld and how to obtain it.

"2. Spot welding different materials, including the effect of thickness of sheets.

"3. Electrode materials.

"4. Seam welding — control, electronics, techniques.

"We desire to present some of this information in our industrial electronics course."

There were numerous essentially duplicating requests, but again there is a limit: "We are already handing out to the students so much additional detailed literature that I doubt if they would pay adequate attention to any further material on welding."

## XX. ENCOURAGING WELDING EDUCATION

In addition to the matter of textbooks and other suggestions previously discussed, specific suggestions were received for providing ways and means to further more welding education within the undergraduate framework. Among these were:

(*a*) "I feel that the American Welding Society should investigate the present efforts of the Foundry Educational Foundation in providing summer employment and scholarships for able undergraduate students who might go into this field. I would particularly like to underline the viewpoint of the F.E.F. in selecting not only metallurgists but also business and mechanical engineering majors. I believe such scholarships in welding engineering could be useful in attracting civil and electrical engineering majors to the field of welding. Such an effort pursued for a number of years can develop sufficient momentum so that it may be relaxed from a financial standpoint in a few years and will continue under its own momentum thereafter. This we consider very important because we must of necessity concentrate on materials and processes in the foundation courses in Metal Processing. It is only to the students who elect professional courses in welding that we can give a 'feel' for design.

"In foundry engineering before the start of the scholarships, we had about one to three bachelor theses students per year; now we have about thirty. In welding engineering we have only one to four theses per year."

"I believe this state of affairs can be improved provided that the industry in cooperation with the American Welding Society can join together to provide for a number of years modern apparatus and scholarships."

"In closing let me emphasize that our Instructing Staff is at all times interested in the efforts of the Educational Committee of the American Welding Society."

It should be pointed out that some schools object to this outlined procedure. They feel this proposed procedure is noncompatible with training in fundmentals and there is also some aversion to commercialism.

(*b*) Enlist the aid of the engineering professors by legitimate, professional and understanding cooperation. Present the subject on its own merits. Avoid bias, overemphasis and commercialism.

"I am interested and should like to help the A.W.S."

(*c*) Further encourage students to participate in the preparation of theses in some form of the welding problem and to prepare and enter original papers in local or national competitive contests.

"Another way in which we have attempted to encourage study in this field on an extracurricular basis is by giving publicity to the national contests in welding design. One of our students was a winner in one of these contests last year."

"One of his advanced students won a $1500 prize for the design of a welded bridge."

(*d*) "May I suggest that you enlist the cooperation of the appropriate committees of the Founder Societies and of the A.S.E.E. Their contacts and sug-

gestions might prove to be of mutual value. There is always the advantage of numbers."

(*e*) Encourage students and instructors to take inspection trips into industrial plants and encourage industry to invite engineering students and instructors to make such trips.

"My past experience has been that by taking students into the actual shops where fabrication is being done gives them a much more lasting impression than by any other method."

(*f*) Encourage instructors to spend summers in industry and encourage industry to make suitable arrangements for instructors to find stimulating and profitable employment during such periods.

(*g*) Encourage "people who are authorities on welding and principles of welded design to come and give lectures to the students."

(*h*) Encourage more widespread usage and distribution of available motion picture films (List available from Executive Secretary, AWS, 33 W. 39th St., New York, N. Y.).

(*i*) "We could use demonstration models of specialized welding equipment if it were to be made available."

(*j*) "Perhaps local A.W.S. member contacts with the teachers of engineering would be of value. If the teacher realizes that the potential employer of his students has a specific desire, and can justify it, I am sure that attention will be generally given, within reason."

(*k*) More laboratory facilities are needed by some institutions. Laboratories are expensive.

"However, recommending the laboratories is one thing and that of providing the facilities, another; and, as you well know, providing equipment for the instruction of student engineers in machine shop practice and welding design is a very expensive proposition. Since an educational institution does not operate on a profit basis, we are unable to provide these facilities due to the high cost involved."

"In expressing my personal opinion, I think it is up to the various industries as a group to assist the educational institutions in providing such equipment, for I think in the long run that they will benefit to a considerably greater extent than the cost involved in providing such facilities. This is my viewpoint on this matter, and I am ready to go ahead on instruction in the field of welding design and machine shop work; but the majority of educational institutions do not have sufficient funds necessary for providing such facilities."

(On the other hand, if every corporation contributed to every worthy cause for which they are requested to make contributions, little would be left to operate the business.)

(*l*) "In our graduate courses the most effective way to promote teaching of welding design would be for industrial organizations to make funds available for small scale graduate research. It would seem very helpful to set up a definite program to encourage and support research and thesis study on a graduate level in welding design and engineering."

(Actually, there is an extensive University Research setup of long standing, with the various institutions on the one hand and the Welding Research Council, 33 W. 39th St., New York, N. Y., on the other hand.)

(*m*) Provide employment assistance to graduates—"it would be highly important to know what possibilities of placement there would be for students specializing in this field."

(*n*) "To close the gap between out-of-date textbooks and the frontiers in practice, periodic summaries of trends and research would greatly assist the instructor. Such progress reports need not be lengthy. Closer Industry and University relationships are necessary

for a better appreciation of the problems of each. Your inquiry is a step in this direction."

(*o*) Do not carry this to an extreme however because, "At present, great quantities of good material from kind and helpful manufacturers and societies go directly to the wastebasket because we must decide what we can do and what we can't."

## XXI. THE REMAINING CHALLENGE

"I agree with you that we could do more toward advancing the subject of welding in the colleges, and it is something we must face in the near future; but at present, at least for the Civil Engineering student, the question is, how?"

A partial answer is given herein by the many educators in their own words. Another portion can, well within the bounds of propriety, be provided by the combined efforts of the A.W.S. Educational Committee. The writer of this report refrains from individual recommendations at this time. That is the function of the full Committee.

# BOOK REVIEW

## "SHIPS FOR VICTORY"

By Frederic C. Lane

With the Collaboration of

Blanche D. Coll, Gerald J. Fischer, and David B. Tyler

Publisher: The Johns Hopkins Press, Baltimore, Md. Price $12.50

Reviewed by Captain Robert B. Madden, U.S.N.

As the subtitle ("A History of Shipbuilding under the U. S. Maritime Commission in World War II") indicates, this book presents an extremely thorough and interesting review of all phases of the work of the Maritime Commission from 1939 through 1945. It is the story of the production of over 55 million dead weight tons of shipping.

The author began the preparation of the book under a contract with the Maritime Commission, but when the Commission's funds were reduced, completed the task as a private individual. However, at all times he had unrestricted access to the Commission's files, and obtained much of his information from personal interviews with the people concerned.

"Ships for Victory" describes in great detail the relations of the Maritime Commission with the White House and Congress, with other government agencies such as WPB and WSA, with shipyard management and with organized labor. It describes the organization and organizational changes at various times during the war period, as well as the relationships between the Washington headquarters and the regional offices.

A detailed discussion of the machinery and hull features of the Liberty and Victory ships, as well as the "standard types"—C1, P4, T1, etc.—is included. The cracking of the welded ships and the resultant criticisms and corrective measures are analyzed.

The dealings with shipyard managements, including arrangements for setting up management forces, changing of unsuccessful managements, contractual relations and the day-to-day means of keeping the "pressure" on the shipyards is set forth in considerable detail. Descriptions of the various shipyards and their various production methods are also included. Of special interest is the attention given to the recruitment, training and housing of the labor force, and the dealings with organized labor. Finally, the system of priorities, the scheduling and the financial problems are all thoroughly examined.

The language of the book is unusually clear and direct, and there are a multitude of charts, photographs, and other figures to supplement the text. This is without a doubt a very important book, and one that should be read by all individuals interested in the shipbuilding profession.

The Society has learned with deep regret of the death of the following since the publication of the August, 1951, issue:

FIKE, CHARLES H., Civil Member

MEANEY, JOSEPH A., Civil Member

SCOFIELD, HOWARD E., Associate Member

The Society takes much pleasure in announcing that the following have been admitted to membership since the publication of the August, 1951, issue.

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# ASSOCIATION NOTES

## ORIGINAL ARTICLES

The editor of the JOURNAL is most anxious to obtain manuscripts of original articles on subjects of interest to naval engineers. Any manuscript accepted for publication becomes the property of the Society which copyrights it upon publication. Authors are paid from $40.00 to $150.00 depending upon length, interest and professional value.

The rules for manuscripts are as simple as we can make them.

1. They must be legible (typewritten, double-spaced preferred) since no proof is submitted to authors for correction prior to printing.

2. Single copy only is required.

3. Mathematical formulae used must be set up, preferably by hand printing, so that there can be no question as to symbols, subscripts and exponents.

4. Any drawing submitted must be black on white. A cloth or paper tracing is acceptable but not required.

5. Photographs may be negatives, but glossy prints are acceptable.

6. Include on a separate page a short biographical sketch(es) of the author(s). 50 to 100 words for each author is desired.

Manuscripts should be mailed addressed to:

Secretary-Treasurer
American Society of Naval Engineers
605 F St., N. W.
Washington 4, D. C.

Manuscripts accepted will not be returned unless specifically requested by the author. If returned, they will be in the condition which has resulted from the work of the printer and the engraver. Immediately following publication, the author is furnished 10 reprint copies of his article free of charge. Additional copies may be purchased from the Society if the request is received 30 days prior to the publication date which is the 25th of the issue month. Estimate of cost of additional reprints, which will vary with the nature of the article and the number of copies ordered, will be furnished on request as soon as possible after the article is set up.

Manuscripts not accepted will be returned, postpaid, by the Society.

Manuscripts which are accepted will be published in the earliest JOURNAL which has not yet been closed (60 days before publication) and for which insufficient material is already on hand.

### Subject Matter and Authors

To assist the editor in programming future issues, the help of all members is solicited. To make it easy, the last page in this issue is readily detachable as you will find. This page has blanks for two entries.

*(a)* What subject would you, as a member, like to see covered by an article in the JOURNAL.

and

*(b)* Who do you consider best qualified to prepare such an article authoritatively, and what is his address (if you know).

Any of these forms which are filled in and mailed to the Society will be received with thanks and the editor will follow up to get the suggested articles prepared.

## PHOTOGRAPHS

Photographs of current or historical interest to readers of the JOURNAL are desired. Any which are accepted by the Society will be purchased by the Society at a standard price of $5.00 each. Such purchase *will not* include any copyright by the Society, but the contributor must hold the Society free from any charge of violation of any previous copyright.

## NOTICE OF DEATHS

The Society has no satisfactory machinery for obtaining notice of deaths of members. It is particularly desired that we receive such notice upon the death of any past officer, past member of the Council or member of more than twenty years' standing with photographs and short obituaries. It will be appreciated greatly if any member who learns of the death of a member will advise the Secretary-Treasurer.

## SOCIETY LAPEL BUTTONS

Shown below is an illustration of the lapel button of the Society. It is believed that it will be conceded that this is a very fine dignified insignia. It is one-half inch in diameter.

The oak leaves and lettering are red on a gold background.

It is available to all members at fifty cents (50c) each.

## LIFE MEMBERSHIPS

Any member may now purchase a life membership under the following rules:

*(a)* Any dues paid for the year in which life membership is purchased will be credited to the cost of the life membership.

*(b)* Life memberships are non-transferable and terminate with the death of the member.

*(c)* No refund will be made on account of death or resignation of a life member.

*(d)* Life membership will vary in cost with the age of the member at his next birthday following application, as follows:

| | |
|---|---|
| Over 55 years | $125.00 |
| 40 to 55 years | 175.00 |
| 25 to 39 years | 225.00 |
| Under 25 years | 250.00 |

*(e)* All life memberships paid in shall be protected by a transfer on the books of the Society of Series G, U. S. Government 2½ per cent bonds. Thus a life membership will be established. It will be credited with moneys paid in for life memberships and debited with the regular amount of annual dues for each life member each year.

## LOCAL CHAPTERS

Local Chapters of the American Society of Naval Engineers may now be authorized by the Council. The following rules for recognition of Local Chapters have been adopted by the Council:

*(a)* Twenty or more regular members, Naval or Civilian, may apply for a Charter as a Local Chapter.

*(b)* Each application must be accompanied by a list of members and a copy of local By-laws. The latter must meet the following minimum requirements.

1. All financial dealings of the local Chapter must be independent of the Society and can in no way obligate the Society as a whole. The local chapter shall set up on a non-profit basis. All accounting shall be local.

2. Each active local Chapter shall receive from the Society a grant of $0.50 per year for each naval member, civil member or associate who resides in the local area and who associates himself with the local Chapter. This grant may be used by the local Chapter to defray any necessary expenses, including (a) Letterheads, (b) Notice cards, (c) Postage, (d) Minimum rental allowance, (e) Secretarial service (part time).

3. Any technical papers presented at local chapter meetings, shall be submitted to the Secretary-Treasurer of the Society for consideration for publication in the JOURNAL. Any paper accepted will be paid for at regular rates.

4. Each local chapter shall submit a quarterly report of its activities to the Secretary-Treasurer. These reports must reach Washington, D. C. prior to 15 January, 15 April, 15 July and 15 October. This report shall contain a list of active local members as of the first day of the quarter for the purpose of computing the amount of grant.

5. Associate members of the Society shall be eligible for membership in a Local Chapter, entitled to all the privileges of other members except voting and holding office.

## REPORT OF AUDIT COMMITTEE

Rear Admiral Louis Dreller, USN, Ret'd. 30 August, 1951
3260 Gunston Road
Alexandria, Virginia

Dear Admiral Dreller:

The committee which you appointed to audit the accounts of the Secretary-Treasurer of the American Society of Naval Engineers for the calendar year 1950, met at the residence of Mr. A. G. Fessenden, Clerk of the Society, on 23 August, 1951. The entire committee was present, consisting of myself as chairman and Captain W. B. Armstrong, USNR, and Mr. John F. Hanlon as members, in accordance with your letter of 28 August, 1951. The Secretary-Treasurer, Captain James E. Hamilton, USN, Ret'd, was also present.

The committee determined that the accounts of the Society for the year 1950, are in order and have been carefully kept. A statement of the income and expenditures and a balance statement, signed by the members of the committee, are appended.

As chairman of the committee, I sighted the Society's securities, a list of which is appended. The Secretary-Treasurer was also present at the sighting.

Respectfully,

R. B. MADDEN

## THE AMERICAN SOCIETY OF NAVAL ENGINEERS, INC.

### FINANCIAL STATEMENTS, 1950

### TRIAL BALANCE

| | | | |
|---|---|---|---|
| Cash | | $ 1,179.66 | |
| Accounts receivable: | | | |
| Advertisements | $ 2,956.95 | | |
| Dues | 2,805.85 | | |
| Sales | 189.45 | | |
| Subscriptions | 337.75 | $ 6,290.00 | |
| Investments: | | | |
| U.S. Defense Bonds, Series G | $58,000.00 | | |
| Washington Gas Light Co. Bonds | 997.50 | 58,997.50 | |
| Furniture | | 95.00 | |
| Income (Publication): | | | |
| Advertisements | $ 7,322.50 | | |
| Dues | 22,449.01 | | |
| Sales (General) | 552.83 | | |
| Sales (Society Buttons) | 18.00 | | |
| Subscriptions | 10,933.55 | | $ 41,275.89 |
| Expenditures (Publication): | | | |
| Printing | $28,732.69 | | |
| Engraving | 4,236.98 | | |
| Manuscript | 3,010.00 | | |
| Postage | 473.24 | | |
| Commission | 182.15 | | |
| Exchange | .90 | 36,635.96 | |
| Interest on Investments | | | 1,450.00 |
| Banquet, 1950 | | | 589.66 |
| General Expense | | 3,525.66 | |
| Salaries | | 4,676.00 | |
| Current Profit & Loss | | 5,341.50 | |
| Dues Paid in Advance | | | 359.00 |
| Subscriptions Paid in Advance | | | 6,309.75 |
| Advertisements Paid in Advance | | | 212.50 |
| Capital Account | | | 66,544.48 |
| | | $116,741.28 | $116,741.28 |

## Statement of Income and Expenditures

### Expenditures

| | | | |
|---|---|---|---|
| Publication: | | | |
| Printing | | $28,732.69 | |
| Engraving | | 4,236.98 | |
| Manuscript | | 3,010.00 | |
| Postage | | 473.24 | |
| Commission | | 182.15 | |
| Exchange | | .90 | $ 36,635.96 |
| Salaries | | | 4,676.00 |
| General Expense | | | 3,525.66 |
| Current Profit & Loss | | | 5,341.50 |
| | | | $ 50,179.12 |

### Income

| | | | |
|---|---|---|---|
| Publication: | | | |
| Dues | $22,449.01 | | |
| Advertisements | 7,322.50 | | |
| Sales (General) | 552.83 | | |
| Sales (Society Buttons) | 18.00 | | |
| Subscriptions | 10,933.55 | $ 41,275.89 | |
| Interest on Investments | | 1,450.00 | |
| Banquet, 1950 | | 589.66 | $ 43,315.55 |
| NET LOSS | | | $ 6,863.57 |

## BALANCE STATEMENT

| | | | |
|---|---|---|---|
| Total Assets January 1, 1950..... | | | $ 66,544.48 |
| Assets December 31, 1950: | | | |
| Cash ..... | | $ 1,179.66 | |
| Accounts Receivable: | | | |
| Advertisements ..... | $ 2,956.95 | | |
| Dues ..... | 2,805.85 | | |
| Sales ..... | 189.45 | | |
| Subscriptions ..... | 337.75 | 6,290.00 | |
| Investments: | | | |
| U.S. Defense Bonds, Series G..... | $58,000.00 | | |
| Washington Gas Light Co. Bonds... | 997.50 | 58,997.50 | |
| Furniture ..... | | 95.00 | |
| | | $ 66,562.16 | |
| Liabilities (Accounting Only) | | | |
| Advertisements Paid in Advance.... | $ 212.50 | | |
| Dues Paid in Advance ..... | 359.00 | | |
| Subscriptions Paid in Advance ..... | 6,309.75 | 6,881.25 | |
| Total Net Assets December 31, 1950.. | | | 59,680.91 |
| NET LOSS ..... | | | $ 6,863.57 |

Respectfully submitted,

J. E. HAMILTON,
*Secretary-Treasurer*

Audited and Found Correct

COMMANDER R. B. MADDEN, USN
CAPTAIN W. B. ARMSTRONG, USNR } Audit Committee
MR. JOHN F. HANLON

## ASNE Securities

U. S. Savings, Bonds, Series G:

Dated April 1, 1943: Purchased April 29, 1943:
Six $1000 Bonds, Serial Nos. M1603025G, M1603026G, M1603027G M1603028G, M1603029G, M1603030G

Dated January 1, 1944: Purchased January 21, 1944:
Five $1000 Bonds, Serial Nos. M2320993G, M2320994G, M2320995G, M2320996G, M2320997G

Dated June 1, 1944: Purchased June 13, 1944:
Five $1000 Bonds, Serial Nos. M2774191G, M2774192G, M2774193G, M2774194G, M2774195G

Dated July 1, 1944: Purchased July 8, 1944:
Five $1000 Bonds, Serial Nos. M2939454G, M2939455G, M2939456G, M2939458G, M2939900G

Dated December 1, 1944: Purchased December 9, 1944:
Ten $1000 Bonds, Serial Nos. M3305689G, M3305690G, M3305691G, M3305692G, M3305693G, M3305694G, M3305695G, M3305696G, M3305697G, M3305698G

Dated June 1, 1945: Purchased June 15, 1945:
Twelve $1000 Bonds, Serial Nos. M3686826G, M3686827G, M3686828G, M3686829G, M3686830G, M3686831G, M3686832G, M3686833G, M3686834G, M3686835G, M3686836G, M3686837G

Dated September 1, 1946: Purchased September 23, 1946:
Three $5000 Bonds, Serial Nos. V717388G, V717389G, V717391G

The above mentioned bonds carried on our books at face value. Their present worth is shown on each bond.

Washington Gas Light Company, 5% coupon, Non-callable, Due Nov. 1, 1960, Purchased December 4, 1929. Two $500 Bonds, Serial Nos. 9167 and 9606.

Carried on our books at $997.50. They are worth more than their face value.

## Business of the Society

From: ASNE AdHoc Committee
To: ASNE Council

Subject: ASNE Financial Status

Reference: (a) ASNE Council Meeting of 26 June, 1951

1. On the occasion of the ASNE council meeting on 26 June, 1951, the president appointed a committee consisting of Captain Dolan, Chairman, Captain Hamilton, Member, and Mr. Engel, Member, "to investigate the entire question of an appropriate business staff and equitable salaries to enable the Society to carry on its business in an efficient and orderly manner and within the income of the Society, the committee to report to the Council its recommendations not later than 15 September, 1951."

2. Your committee has taken a liberal interpretation of its assignment and has accordingly reviewed all financial aspects of the Society. A discussion thereof, together with the committee's comments and recommendations follows:

a. *Budget*—The Society has never operated under an approved budget. Apparently, the Secretary-Treasurer has, of his own volition and with remarkable success, operated the business of the Society under some kind of an unofficial budget determined by himself. It is considered that the Council has the responsibility to fix an annual budget, and it is the unanimous recommendation of the committee that the Council approve a budget on an anuual basis commencing with the calendar year 1952. Accordingly, a proposed budget for the calendar year 1952 is submitted as attachment 1.

b. *Dues*—Current annual dues fixed by the present By-Laws are $7.50. It is the unanimous recommendation of the committee that no change be made at this time.

c. *Subscriptions to ASNE Journal*—The current annual subscription rate for the Journal is $9.00. It is the unanimous recommendation of the committee that no change be made at this time.

d. *Advertising Rates in ASNE Journal*—The current advertising rates in the Journal are $250.00 per full page, $150.00 per half page, and $100.00 per quarter page. It is the unanimous recommendation of the committee that no change be made at this time. However, the committee recommends that the Secretary-Treasurer initiate an immediate campaign to secure additional advertisements in the Journal, and that at such time as circulation has increased to an extent to warrant such action, consideration be given to an increase in the advertising rates.

e. *Annual Banquet*—The activities of the Society consist primarily of the Journal, which is published quarterly, and the annual banquet. It is the unanimous recommendation of the committee that the annual banquet be self-supporting. However, the committee is loathe to make any recommendation concerning certain aspects of this banquet and, accordingly, submits the following for consideration by the Council. Current practice is to charge members at the rate of $10.00 per plate

and non-members at the rate of $12.50 per plate, with the stipulation that non-member attendance be limited to one guest per member. Aside from the inconvenience of the price differential between members and non-members, there has arisen the problem of staying within the physical space limitations of the Statler Hotel which has the only banquet room in Washington with the required capacity. The two basic questions are:

1. Should price differential between members and non-members be abolished or retained?

2. If retained, should it be at ratio of $10.00 to $12.50, or at some other ratio such as $10.00 to $15.00?

f. *Salaries of ASNE Staff*

1. The committee unanimously reaffirms the Council action at the meeting of 26 June, 1951 to :

(a) Raise the salary of the Clerk to $300.00 per month as of 1 July, 1951

(b) Employ an assistant to the Clerk at a salary of $200.00 per month.

(c) Pay Mr. Fessenden $150.00 per month for life upon his retirement as an employee of the Society.

2. The committee, by a majority vote, recommends that the salary of the Secretary-Treasurer be increased to $300.00 per month commencing 1 October, 1951.

3. The committee, by a majority vote, recommends that the salary of the Assistant Secretary-Treasurer be increased to $100.00 per month commencing 1 October, 1951.

g. *By-Laws*—The committee unanimously recommends that the first line of article 11 of the By-Laws be amended by substituting the word "may" for "shall." This change would make the appointment of an Assistant Secretary-Treasurer optional and would thus give the Council more leeway in the matter of salaries.

h. *Secretary-Treasurer*—The committee discussed at considerable length the question as to whether the Secretary-Treasurer should be an elective position, as now provided by the By-Laws, or an appointive position. It is considered that, in any event, he should be a commissioned officer of the regular Navy, Marine Corps, or the Coast Guard, and a member of the Council, as now provided by the By-Laws. The committee submits no recommendation with respect to the manner in which the Secretary-Treasurer is selected.

3. It is requested that the committee be dissolved.

S/J. E. Hamilton S/F. H. Engel S/W. A. Dolan, Jr.

## AMERICAN SOCIETY OF NAVAL ENGINEERS

*Budget for 1952*

| | | |
|---|---|---|
| **Predicted Income:** | | |
| Dues (2850 @ $7.50) | | $21,375.00 |
| Advertisements | | 7,500.00 |
| Subscriptions (1800 @ $9.00) | | 16,200.00 |
| Sales | | 350.00 |
| Interest on Investment | | 1,500.00 |
| Banquet (1500 @ $12.50) | | 18,750.00 |
| Total Predicted Income | | $65,675.00 |
| **Authorized Expenditures:** | | |
| Salaries | | $10,800.00 |
| Rent | | 480.00 |
| Office Equipment | | 250.00 |
| General Expense | | 2,200.00 |
| Postage | | 400.00 |
| Profit & Loss (Delinquent dues) | | 1,000.00 |
| Journal | | |
| Printing (incl. mailing) | $25,800.00 | |
| Engraving | 2,400.00 | |
| Manuscript | 2,800.00 | 31,000.00 |
| Banquet | | 18,000.00 |
| Total Authorized Expenditures | | $64,130.00 |
| Predicted Gain | | $ 1,545.00 |

Approved by Council: 9/10/51

LOUIS DRELLER
*President, Attest.*

Proposed: 9/10/51

J. E. HAMILTON
*Sec. Treas.*

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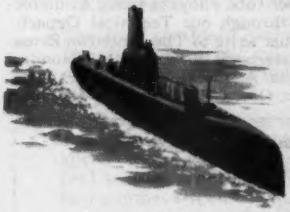
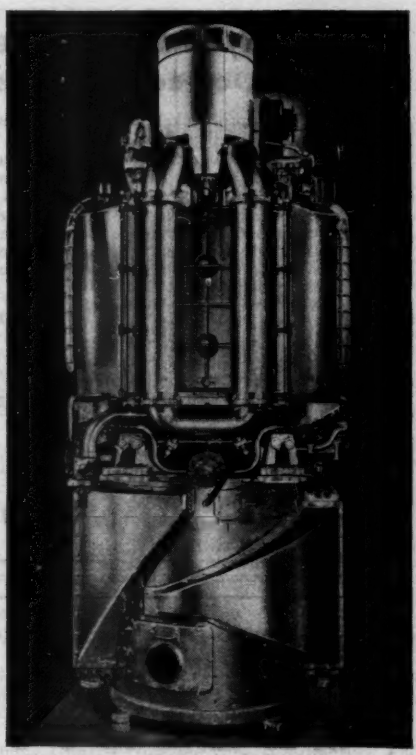
Cleveland Diesel Engine Division

GENERAL MOTORS





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*U. S. Patent No. 2,074,601

**ANACONDA Cupro-Nickel-755:**
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Resists corrosion
Costs less

**ANACONDA Cupro-Nickel-755 composition:**

| | | | |
|---|---|---|---|
| Copper 88.35 | | Manganese 0.40 | |
| Nickel 10.00 | | Iron | 1.25 |

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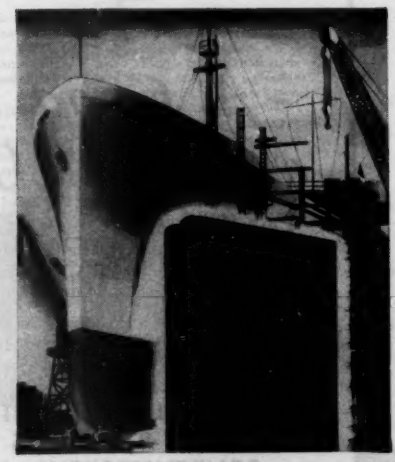

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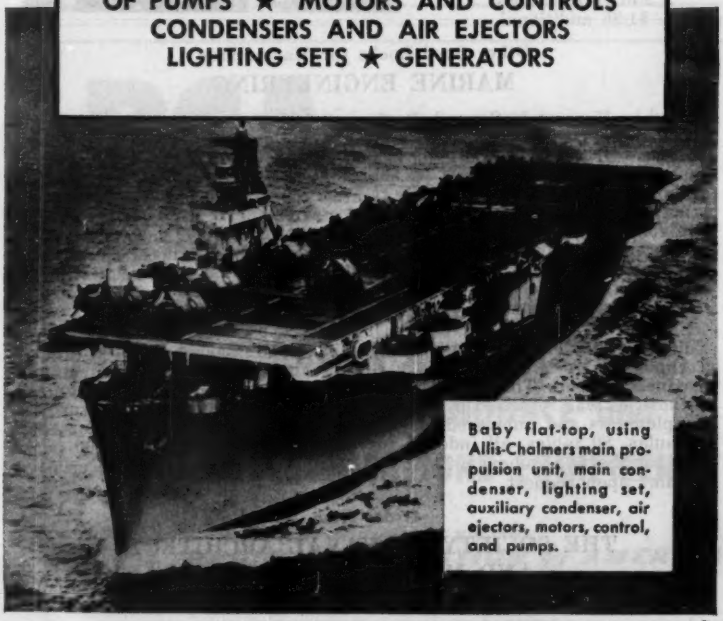

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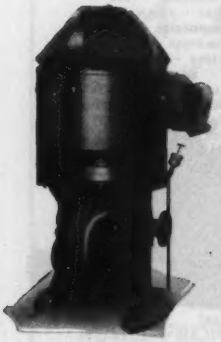

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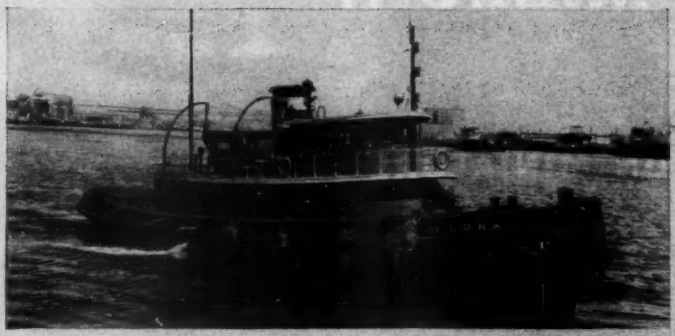

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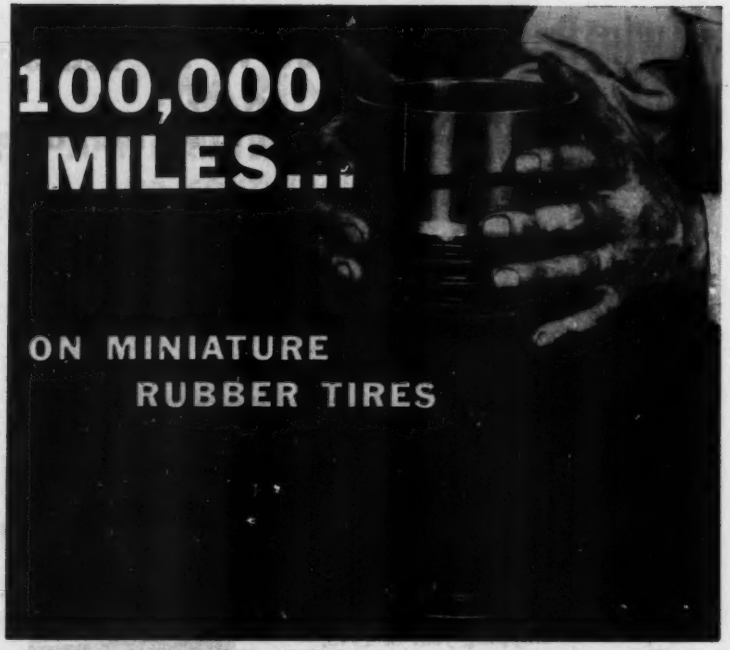


Photograph courtesy of Cummins Engine Company, Inc., Columbus, Indiana

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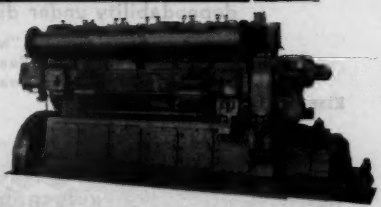

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*See reverse side for required qualifications for various classes of membership

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